

**Application of Color Powder Paint
in the Automotive Industry**

by

Bevin Barberich

Bachelor of Science and Engineering in Mechanical Engineering,
Princeton University (1997)

Submitted to the Department of Mechanical Engineering and the Sloan School of
Management in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Mechanical Engineering and
Master of Business Administration

In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2004

©2004 Massachusetts Institute of Technology. All rights reserved.

Signature of Author _____

Department of Mechanical Engineering
Sloan School of Management
May 2004

Certified by _____

u

ll

Joel Clark, Thesis Supervisor
Professor of Material Science and Engineering

Certified by _____

v

Charles Fine, Thesis Supervisor
Professor of Management

Accepted by _____

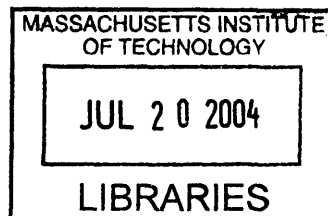
David Wallace
Professor of Mechanical Engineering

Accepted by _____

Margaret Andrews, Executive Director of Masters Program
Sloan School of Management

Accepted by _____

Ain Sonin, Chairman, Graduate Committee
Department of Mechanical Engineering



BARKER

9



Application of Color Powder Paint in the Automotive Industry

By
Bevin Barberich

Submitted to the Department of Mechanical Engineering and the Sloan School of Management on May , 2004 in partial fulfillment of the Requirements for the Degrees of Master of Science in Mechanical Engineering and Master of Business Administration

Abstract

Both color keyed and color specific liquid primers have been used successfully in automotive paint application, reducing the use of costly topcoat materials. Generally, color keyed primer is close in color to the topcoat and is applied to the exterior surfaces of the vehicle body. Color specific primer identically matches the topcoat material color, and can be used as a replacement for topcoat on interior surfaces. Application of color *powder* paint primer would provide for additional cost savings, more environment-friendly manufacturing, and higher customer satisfaction. Recent technology breakthroughs have led to the technical feasibility of applying multicolor powder paint with full reclaim and therefore 100% material utilization. The field feasibility of applying multicolor powder paint in an automotive manufacturing facility is being assessed and validated by GM.

More specifically, GM has developed the GM Canister Powder Paint Delivery System to meet the challenges of color powder paint application. In anticipation of multicolor powder paint application, GM is completing its Manufacturing Systems Qualification (MSQ) Process for the Canister System. Due to the newness of the enabling technology, GM is investigating all aspects of materials, process designs, facilities, operations, and people, for the implementation of color keyed/color specific powder paint primer into new GM paint shops.

Similar to GM's MSQ Process, qualification requirements in the pharmaceutical and medical device industry attest to the importance of validation in the implementation of new manufacturing technology. Beyond its technical purposes, validation can serve as a bridge between development and operation. During development, formal and relational contracts with suppliers should be established to provide incentives for the supplier to perform throughout validation and commissioning. Involving the plant in validation along with suppliers is one means of education and thus empowerment, a key phase of organizational change as described by Professor Shoji Shiba. Leadership can use several change management techniques to help prepare the plant organization for operation of the new manufacturing technology.

Thesis Supervisors

Joel Clark, Professor of Material Science and Engineering

Frank Field, Senior Research Associate, Center for Technology, Policy, and Industrial Development

David Wallace, Professor of Mechanical Engineering

Charles Fine, Professor of Management, Sloan School of Management

Preface

This thesis is based upon a six-and-a-half month internship with the Technology Development and Validation (TD&V) group of the Paint and Polymers Engineering (P&PE) division of General Motors. At the time of the project (Summer and Fall of 2003), TD&V was in the process of developing a multi-colored powder paint primer application system, its first internally developed technology. The primary goals of my internship project were to:

- Complete GM's Manufacturing Systems Qualification (MSQ) process for the multi-color powder paint primer system, and help prepare the system for plant operation.
- Document how the system design meets the challenges of color-keyed and color-specific powder primer systems, and GM's business approach for commercializing the internally generated idea.

As part of the MSQ process, I conducted lab testing at the Warren Tech Center and assisted with production testing at one of GM's assembly plants. After translating final finish requirements into functional requirements, I was able to define and complete tests replicating or simulating operational conditions and constraints. This thesis includes summaries of the two reports I wrote for GM, detailing the procedures, results, and technical analyses conducted for MSQ. The validation process not only confirmed that the system met functional and durability requirements, but also provided information about operational and maintenance requirements for the new system. I communicated this information to the project team at periodic meetings, to allow for easier installation and commissioning.

My internship project contributed to the larger goal of implementing the new multi-color powder paint primer system at GM. Although my role was primarily technical, my management training led me to take a higher level view. I identified the following problem statement: What factors, in addition to a thorough validation process, would lead to a smooth implementation? For analysis, I collected non-technical data through formal and informal interviews with GM managers, engineers, and plant staff; with supplier representatives; and with representatives from other automotive companies. This thesis thus addresses the technical challenges of implementing a new automotive coating application technology, as well as the 'soft side' complications caused by supplier relations and organizational culture and politics.

For proprietary reasons, the specific validation data collected will not be presented and actual suppliers will not be listed.

Acknowledgements

I would like to thank General Motors, especially Eric Stevens and Tom Meschievitz, for sponsoring this work. In addition, I would like to thank the Leaders for Manufacturing program for its support. In particular, I would like to acknowledge:

Frank Field, Joel Clark, Charles Fine, and David Wallace for their advice and encouragement;
Sheila Kia and Chris Murphy for serving as excellent role models;
DanaMorgan, Brian Prylon, Linda Gerhardt, Gary Hildebrand, and Mark Johnson for welcoming me into the TD&V group;
Scott Woodfield and Company for showing me the ropes in the lab;
Norman Goodman, Peter Gray, James Hiller, Glen Santelices, Paul Thoreson, Fred Blair, Joe Claya, Frank Rauch, Dave Sufczynski and everyone on the Project Team;
Joseph Klobucar, PE, and Rick Ostin;
Gunnar van der Steur and everyone at EFC;
Dick and Kathy Roher;
Laurent Jeanningros;
Tina Poquette and my “Detroit” friends;
Monica, Patrick, and Jessica Barberich for their support in everything I do.

I dedicate this thesis to Sheila Barberich, who always said my sister and I were the smartest kids.

Table of Contents

Abstract	3
Preface	5
Acknowledgements.....	7
Table of Contents.....	9
Chapter 1: Introduction.....	11
1.1. Industry History.....	11
1.2. Recent Industry Accomplishments.....	14
1.3. Industry Future: Low-Emission Technology	16
1.3.1. Developing the Alternative Coatings System	17
1.3.2. Achieving Multi-Color Capabilities of Liquid with Powder.....	19
Chapter 2: Innovation for the Application of Color Powder	23
2.1. MSQ Process	25
Chapter 3: From Innovation to Implementation: Understanding the Industry	27
3.1. Path to Commercialization	27
3.2. Supply Chain Complications.....	31
Chapter 4: Technology Transfer: Criteria for Success	39
4.1. Validation of System to meet Technical Requirements	39
4.1.1. Goals of MSQ Process	39
4.1.2. Challenges to MSQ Process	40
4.1.3. Benchmarking: Pharmaceutical Industry and Medical Device Industry.....	42
4.1.4. Recommendations	45
4.2. Preparation of Plant to meet ‘Soft-side’ Requirements.....	47
4.2.1. Organizational Factors	47
4.2.1.1. Strategic Design	47
4.2.1.2. Political Lens	49
4.2.1.3. Cultural Lens	49
4.2.2. External Reference: PSA Peugeot Citroen’s Mulhouse Plant.....	50
4.2.3. Internal Benchmarking: Past implementations of new paint technology at GM.....	52

4.2.4.	Methods and Recommendations for Change Management.....	53
4.2.4.1.	Introducing Change	53
4.2.4.2.	Managing Installation and Adoption of New Technology.....	57
Chapter 5: Summary and Conclusions		63
5.1.	Summary	63
5.2.	Next Steps.....	63
5.3.	Conclusion.....	64
Bibliography		65

Chapter 1: Introduction

1.1. Industry History

The basics of automotive coatings have remained the same for more than ten years: The automotive painting process consists of five steps. A zinc phosphate coating is the foundation of the entire paint system. In the next step a corrosion resistant coating known as the electro-deposition or E-Coat is applied. Both the phosphate and E-Coat are usually applied by immersing the entire vehicle into a coating solution. Subsequent to the E-Coat, a primer/anti-chip coating is applied. The fourth layer is known as the base coat. Base coat gives the vehicle its color. The final coating in the process is the clear coat. The clear coat provides durability, UV protection, and most importantly a high gloss finish.¹

Traditionally, the primer coat, basecoat, and clear topcoat have used organic-based solvents as carriers for the paint resin particles. As the paint cures, the solvent evaporates, creating volatile organic compounds (VOC) emissions that contribute to the formation of lower atmospheric (tropospheric) ozone.² Prompted by the 1977 amendments to the Clean Air Act, which initiated low emissions requirements for the automotive industry, companies including GM began to investigate alternative coatings materials and processes.³

Figure 1 shows the VOC emissions levels required by the series of emissions standards enacted following the 1977 Clean Air Act amendments. During the early 1980's, Reasonably Achievable Control Technology (**RACT**) limits required a dramatic improvement from the traditional solvent-based coatings systems, both lacquer and enamel. High-solids, solvent-based coatings were developed, but did not meet the emissions limits without additional expensive abatement systems. While effectively reducing emissions, abatement systems create new issues through nonproductive costs and excessive energy usage, which contributes to the emission of greenhouse gases.⁴ Instead, waterborne coatings emerged as the liquid alternative to solvent-based paints, and by 1993, industry leaders estimated that 20% of the world's automobile plants were using water-borne basecoats.⁵ At the same time, significant advancements were being made

¹ DeWitt, Charles M. "A Holistic Approach to Automotive Powder Coating." *Massachusetts Institute of Technology*, June 1995, P14-15

² Beuerle, James Edward, Jr. "A Study of Electrostatically applied Powder Paint in the Automotive Industry." *Massachusetts Institute of Technology*, June 1996, P9-11

³ Lis, Karen and Messerly, Eric R. "Powder Primer Surfacer Technology Implementation." *International Body Engineering Conference*, May 23, 1994, P1

⁴ Johnson, Jeffrey C., Joyce, Jeffrey R., Kolarik, William. "Multidimensional Design, Multicolor Powder Primer." *Metal Finishing [H.W. Wilson – AST]*, May, 2000, Vol. 98, Iss. 5, P11

⁵ Bonifant, Ben. "Competitive Implications of Environmental Regulation in the Paint and Coatings Industry." *Management Institute for Environment and Business (MEB)*, Washington, D.C.: 1994, P232

in the application of powder coatings. During the early 1990's, when LAERII more than halved the allowable VOC level, powder paint appeared to be a key element for future low-emissions coatings systems.

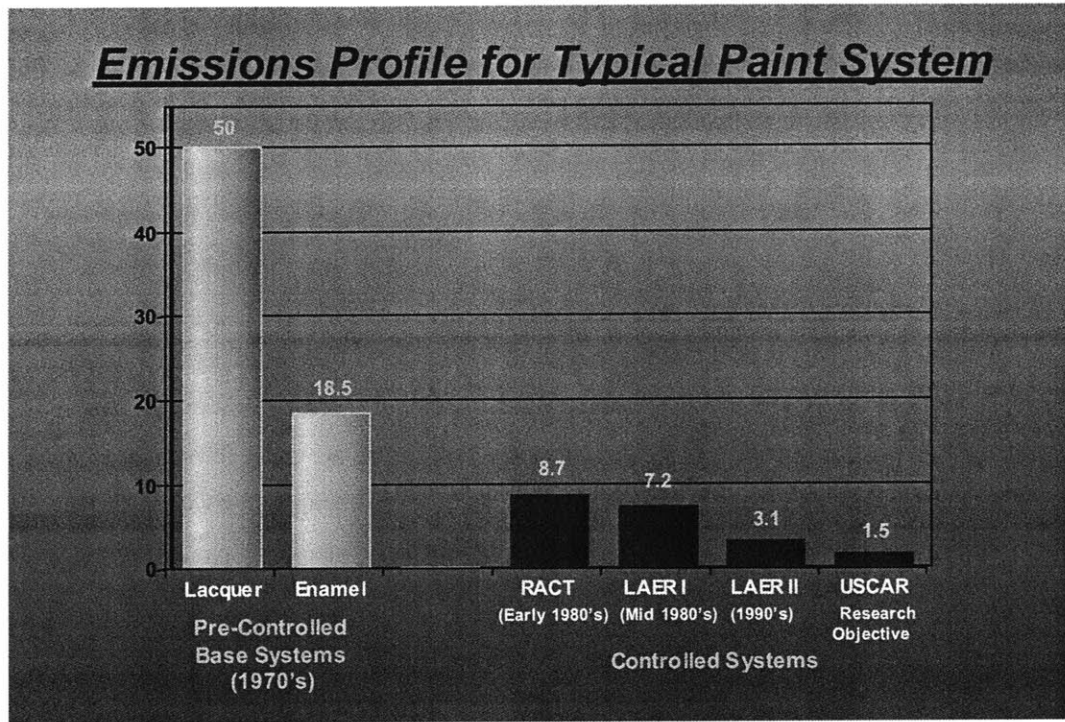


Figure 1: Per Vehicle VOC Emissions Level Reductions Following the 1977 Clean Air Act Amendments⁶

The powder coating process is markedly different from the solvent-based coating process.⁷ Instead of residing in a tank prior to application as liquid paint does, the powder is mixed with compressed air, or fluidized, in a hopper. A venturi pump delivers the powder/ air mixture, via flexible tubing from the hopper to an applicator. The paint is sprayed through the applicator, which is generally a corona-generating device. Passing through the corona, the powder particles pick up a charge. Electrostatic as well as aerodynamic forces convey the charged particle to the grounded part to be coated. As with liquid, parts are coated in an enclosed booth. Instead of collecting oversprayed paint in a sludge tank for disposal, however, powder overspray falls into collectors beneath the booth and is usually sent through a reclaim system so

⁶ Graph supplied by GM's Paint and Polymers Engineering Department

⁷ DeWitt, P6-7

that it can be recycled. After a part has been powder coated, electrostatic forces continue to hold particles to the surface until the job reaches the cure ovens. In the cure ovens, parts are held at approximately 340 deg. F. for 20 to 30 minutes. The curing process at first allows the paint particles to flow, creating a smooth surface. As the curing process progresses, cross-linking begins to occur and continues until the powder thermosets. The result is a high quality and durable appearance.

Powder coatings, in comparison to liquid systems, provide improved resistance to chip and corrosion, with essentially zero emissions of organic compounds as either gaseous or solid waste.⁸ With the advantages of booth air recycling and no need of water, operating costs including energy, cleaning, chemicals for water treatment, waste water, and other wastes can be lowered or even eliminated. Using reclaim and optimizing the manufacturing process also reduce cost significantly.

Early arguments against powder paint included the belief that the application of dry powder could not be controlled to achieve the consistent film thickness and smoothness required for automotive Class-A surfaces. Another concern was that the use of reclaimed powder, which would make the process economically feasible, would introduce too much contamination to reach a consistently acceptable finish.⁹ GM overcame these obstacles with single-color (gray) powder paint primer implementations during the 1980's, beginning in 1982 with the Shreveport, LA, plant.¹⁰ Additional factors seemed to prevent the use of powder coatings for clear topcoat and colored basecoat applications. The inability to rapidly change colors, and difficulties with powder coating metallics, were often cited as major limitations with powder coating.¹¹

In response to the 1990 Clean Air Act Amendments, which would require the EPA to begin enforcing further reductions in VOC emissions within the automotive painting industry, GM decided to join with Chrysler and Ford in improving the powder paint process and expanding the possible applications for powder paint.¹² Operating under the umbrella of the United States Council for Automotive Research (USCAR), the "Big Three" U.S. automakers formed the Low Emissions Paint Consortium (LEPC) in February 1993, to conduct joint research and development related to low-emission paint technologies.¹³ Early in the existence of the consortium, the LEPC agreed to pursue the development of an alternative coatings system that

⁸ Johnson et al., P11

⁹ Johnson et al., P12

¹⁰ Lis and Messerly, P1

¹¹ DeWitt, P12

¹² Beuerle, P9-11

¹³ Meschievitz, T.A., Pearson, R.F., and McLaughlin, E.O.. "USCAR: Automotive Powder Clearcoat Experience." *Metal Finishing [H.W. Wilson - AST]*, August, 1997, Vol. 95, P15

would reduce emissions to only 1.5 VOC units per gallon (reference Figure 1). The proposed system would have the same phosphate and E-Coat.¹⁴ A powder-based primer would replace the solvent-based primer coat. Powder could not be used for the base coat because of the desire for a metallic finish. Instead, a waterborne color coating would allow for a metallic finish similar to that for solvent-based color coats, with reduced emissions. For the topcoat, most of the LEPC's efforts were to revolve around the development of powder-based clear coat.

With the aim of reducing emissions through material and process changes rather than nonvalue, "end-of-pipe" controls, the LEPC encouraged environment-friendly innovation in two main ways.¹⁵ First, it allowed the Big Three to minimize development costs by sharing existing resources and knowledge.¹⁶ Second, the paint supplier community (both materials and applicators) would be much less apprehensive about developing new systems if supported by each member of the Big Three, as opposed to a single automaker.

1.2. Recent Industry Accomplishments

A paper published by GM in March 2002, confirms that over the past ten years, "Cooperative efforts within the material and equipment supply community as well as the automotive industry have enabled migration to future powder coatings."¹⁷

BMW, which uses a PPG Powder Clear Coat (PCC) on the 5- and 7- Series models built at Dingolfing, Germany, has taken the lead with powder-based clear coat.¹⁸ A 1997 report by the LEPC indicated that the powder clearcoat process had yet to be implemented into production "due to considerable challenges in areas such as appearance, defect reduction, durability, recyclability, cost, and process compatibility."¹⁹ Inherent yellowing and lower scratch and mar resistance were cited as reasons that powder clearcoat materials did not perform as well as the best solvent system. PPG, however, has continued development work with BMW on the design of the clear coat flow additive, the surface-active ingredient that affects flow and leveling.²⁰ Currently at Dingolfing more than 1000 cars per day are finished with PCC.

¹⁴ Beuerle, P14

¹⁵ Meschievitz et al., P15

¹⁶ Beuerle, P10-11

¹⁷ Murphy et al. "Multicolor Powder Coating Application of Automotive Primer Surfacer." *Powder Coating*, March 2002, P19

¹⁸ Diem, William. "PSA's New Mulhouse Paint Shop to Use Powder Primer." *WardsAuto.com*, March 20, 2003, P1

¹⁹ Meschievitz et al., P15,20

²⁰ Wimmer, Walter. "Powder Clearcoat, a Leap in Paint Technology." *Automotive Engineering International [H.W. Wilson - AST]*, February, 2001, Vol. 109, Iss. 2, P207

Because the European Union has established national VOC emission ceilings that will take effect within this decade, other European companies are also pursuing alternative coatings.²¹ PSA Peugeot Citroen's new paint shop at its Mulhouse plant has the first application in Europe of a powder primer.²² Mulhouse builds the Peugeot 307, 206, and 206CC, at a rate of 87 cars per hour. The new primer, supplied by BASF Corp. results in a 25% reduction in water discharge and a reduction in the amount of volatile organic compounds reaching the atmosphere. Following the powder primer, the paint booths spray a water-based paint, so only the clear coat is delivered by solvent. Ferrari claims its new paint shop, designed by Fiat Engineering, will be the most advanced in the automotive world when it opens in 2006.²³ The shop plans to use powder-based primer and water-borne paint, for a 10-fold reduction of current levels of solvent emissions by 2010. Because it will coat all Ferrari and Maserati road cars – at a planned volume of 15,000 a year – the paint shop aims for a high degree of flexibility in terms of different models and colors.

PSA Peugeot Citroen is applying multi-color powder primer at Mulhouse. This is a somewhat radical strategy, given that only a few manufacturers have been successfully applying full body single-color powder primers. Several manufacturers have delayed a changeover to powder, due to their requirements for primers to be, at a minimum, color keyed to basecoat colors to improve surface appearance.²⁴ The use of colored liquid primer serves two purposes: it more closely color matches the basecoat to lower its use, and it provides better appearance when the finished coating is scratched or chipped through the basecoat to the primer layer.²⁵ Colored liquid primers are applied either as color-keyed, usually consisting of three to four colors or color families; or as color-specific, which matches primer color to basecoat color.

GM has also focused on matching the multi-color capabilities of powder to those of liquid, particularly with primers. While PSA Peugeot Citroen used commercially available technology for its colored powder primer application, GM developed new technology to address financial, spatial, and cycle time constraints. Unlike the European automotive companies, whose local customers are more likely to consider environment-friendly manufacturing a sellable feature for a vehicle, American companies cannot rely on this increased revenue to help fund process improvements. Instead, GM's innovation, which will be described in the remaining chapters of this thesis, makes the auto company the forerunner in economically applying color powder primer paint.

²¹ Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants [Official Journal L 309 of 27.11.2001].

²² Diem, P1

²³ Robinson, Peter. "Ferrari HQ to Undergo Massive Renovation." *WardsAuto.com*, August 12, 2002, P1

²⁴ Johnson et al., P11

²⁵ Murphy et al., P19

Europe and the US are clearly leading the rest of the world in the adoption of new coating materials and processes. According to Masafumit Kume, director and general manager of the automotive coatings division of Kansai Paint Co. Ltd., “There are no VOC regulations in Japan at this time, although we expect some in the future.”²⁶ Instead the emphasis appears to be on lowering energy requirements, and indirectly carbon dioxide emissions. Kansai has developed a process called “wet-on-wet” that is currently being tested by Toyota and Honda. The process eliminates baking after the primer coat, and thus saves energy, by applying the top coat while the primer coat is still wet. Most Japanese carmakers do have an immediate objective of reducing VOC emissions by 40%, which is achievable by switching to high-solids paints only. Toyota, however, has announced plans to reduce emissions by 65% on all of its manufacturing lines by 2005. Masafumit Kume explained that this goal could be achieved by eliminating the primer coat through the “wet-on-wet” system and switching to high-solid paints for the clear coat and filler. He also noted that converting the primer, filler and clear top coats to water-borne paints would reduce VOC’s by 70%, while switching to a powdered primer coat and hard-solid clear top coat would achieve at least a 75% reduction.

Worldwide, then, automotive companies have recognized that their coating materials and processes must evolve, in order to achieve the VOC emissions levels required by current and imminent environmental legislation. The efforts of all of these companies appear to be converging toward a single view of the future for automotive coatings.

1.3. Industry Future: Low-Emission Technology

The capital required for a new paint shop makes up 30-50% of the capital investment in a new plant.²⁷ The cost is justifiable, though, because a good finish is one of the first things to attract a customer to an automobile. After all, it is often said that, *the paint sells the car*. Throughout the life of the vehicle, the finish continues to be a key indicator of vehicle quality. For example, the JD Power “Body and Interior Quality Rating” is based partly on problems reported with Exterior Paint.²⁸

²⁶ Schreffler, Roger. “Paint is Poised for Cleaner Role, Improved Product.” *WardsAuto.com*, February 15, 2001, P1

²⁷ Nallicheri, Renu Agawal. “Automotive Painting – An Economic and Strategic Analysis.” *Massachusetts Institute of Technology*, December 1993, P5

²⁸ http://www.jdpower.com/cc/auto/auto_terms/auto_terms_b.asp

Unfortunately, of all manufacturing processes for vehicle production, the painting operation also contributes most to the direct environmental emissions.²⁹ Driven primarily by environmental legislation requirements, automotive companies are pursuing the goal of reducing emissions, while maintaining finish quality and without significantly increasing the already high cost of coating vehicles. The automotive industry is on the verge of realizing an improved coatings system. Traditionally solvent-based coatings will be replaced by a combination of alternative coatings: Powder Primer, Waterborne Top Coat, and Powder Clear Coat.

One environmental benefit of the alternative coatings combination, as mentioned earlier, is reduced VOC emissions. A Life Cycle Analysis conducted by the GM Research and Development Center concluded that the combination has additional advantages over the other scenarios considered: waterborne basecoat with solventborne primer and clearcoat, and powder primer with waterborne basecoat and solventborne clearcoat.³⁰ In manufacturing of the materials for the three painting scenarios, the powder primer/ waterborne topcoat/ powder clearcoat combination is associated with the least energy, water consumption, solid waste, and VOC. However, it does exceed other scenarios in Particulate Matter, SO_x, and CO₂-equivalent air emissions. When the paint processes themselves are included in the Life Cycle Analysis, the powder primer/ waterborne topcoat/ powder clearcoat scenario is associated with the lowest life cycle inventories of PM, SO_x, and CO₂ as well. Of course, these inventories do not evaluate the total environmental impacts of the emissions. It is more meaningful to aggregate all the emissions from each plant and consider the resulting contribution to indices such as global warming potential and ozone depletion potential. While the powder primer/ waterborne topcoat/ powder clearcoat scenario has the lowest energy requirements and associated emissions, the aggregate CO₂-equivalent air emissions, which occur primarily during the production of energy (electricity and heat) using fossil fuels, are substantial. Energy conservation measures and an increased use of renewable forms of energy may be able to further reduce the global warming potential for all three of the scenarios.³¹

1.3.1. Developing the Alternative Coatings System

In order to achieve the environmental benefits previously discussed, the materials and processes for each of the alternative coatings must be optimized, while ensuring that the

²⁹ S.Papasavva et al. "Characterization of Automotive Paints: an Environmental Impact Analysis." *Progress in Organic Coatings*, 2001, Vol. 43, P193

³⁰ S.Papasavva et al., P205-206

³¹ S.Papasavva et al., P205-206

individual coatings and processes are compatible. Systems engineering is imperative in developing the multi-coat system. The vehicle body cannot be analyzed alone; the carrier conveying it could introduce contaminants from one paint booth or oven to another. For each coating, the impact of surrounding processes, as well as components common to multiple processes, must be considered.

Material development thus becomes extremely complicated. For example, GM's implementation at Shreveport in 1993 applied a powder primer and then a powder topcoat as blackout on the door frame.³² A polyester/epoxy hybrid chemistry was preferred for the primer, because it would provide outstanding chip resistance and stability. For the topcoat, an acrylic chemistry was preferred, because of its durability characteristics for weathering and chemical resistance. Early in the development program, however, process trials confirmed the presence of small craters when the acrylic blackout was used with a polyester/epoxy hybrid primer. The primer was therefore developed in acrylic chemistry as well.

It should be noted, however, that occasionally different coatings combinations result in unexpected advantages. Case and point, BMW has found that with Powder Clear Coat: spraying difficult bright colors on wide areas of the outer car surface panels is significantly better than using a wet clearcoat system.³³ This improvement is attributed to PCC's lack of solvent action on the basecoat.

Each of the coatings in the system has its own benefits and challenges. With powder clearcoat for example, due to a tradeoff between yellowing and scratch resistance, the percentage of critical color tones (i.e., light metallic colors) can influence overall assessments of finish quality.³⁴ Many features of powder coatings, though, are common to both the primer and clear topcoat. One of the biggest advantages of both powder primer and topcoat is the capability for almost 100% material use through reclaim and closed-loop recycling processes.³⁵

During the 1993 Shreveport implementation, GM identified and began to address some of the enablers for efficient material use of powder paint.³⁶ First was the closed loop powder delivery system, ensuring that the powder material would not be subjected to outside contaminants from the time it left the manufacturer's site until the time it was being applied to the vehicle. Taking into account the company's goal of reusable containers and no cardboard in the paint shop, GM worked with material and equipment suppliers to develop a stainless steel

³² Lis and Messerly, P3

³³ Wimmer, P208

³⁴ *Ibid.*, P208

³⁵ Murphy et al., P19

³⁶ Lis and Messerly, P6&7

reusable tote container. Second, critical to the reclaim system was the collector design. GM manufactured and tested several designs to determine the optimum filter position and wall slope required to successfully extract material for reuse in the system. Finally, reclaimed overspray powder must be sieved before reuse, because of the near-certainty of contamination. Since coating quality is likely to vary if overspray powder is recycled separately from the virgin powder, common practice is to mix virgin and reclaim powder for supply to the application equipment.³⁷

Perhaps the most important enabler for efficient material use of powder is the application process. In coordination with the LEPC, GM has focused on developing tests and procedures for new application equipment to 1) maximize transfer efficiency, and 2) improve film uniformity at reduced film build (paint film thickness).³⁸ Transfer efficiency refers to the percentage of powder sprayed that adheres to the metal car body.³⁹ High transfer efficiency will both minimize the costs associated with recovering and/or disposing of powder, and reduce the need to use recovered powder, which is a potential source of appearance problems. A minimum film build is necessary to prevent underlying coatings from being exposed to UV light, but film build uniformity is important from both an appearance and cost perspective. A lower standard deviation allows for less paint to be used since the mean film build can be targeted closer to the minimum thickness. Much work has been performed to study transfer efficiency and film build characteristics, yet the research must be revisited for each new applicator.

Application equipment can have impacts aside from film build on the quality of powder coating applications. At Shreveport GM discovered that after longer hours of operation, impact fusion and material accumulation on some application equipment resulted in an increase in dirt on the vehicles.⁴⁰ Another Shreveport lesson was that the compressed air system is a critical piece of any powder system. Air provided from the existing mild steel system contained cutting oil, which caused severe cratering of the coating that could only be seen in the final product. Subsequent compressed air systems were installed using stainless steel and clamp fittings.

1.3.2. Achieving Multi-Color Capabilities of Liquid with Powder

As detailed in the preceding discussion, much progress has been made in optimizing the powder coating process, but primarily for single-color application (gray or clearcoat). In order

³⁷ German, Shaun. "Ultrasonic Deblinding System Improves Powder Coating Sieving." *Paint & Coatings Industry*, Troy: July 2003, Vol. 19, Iss. 7, P86

³⁸ Meschievitz et al., P22

³⁹ Beuerle, P26

⁴⁰ Lis and Messerly, P8

for the powder primer/ waterborne topcoat/ powder clear coat system to be as robust as existing liquid systems, however, *multi-color* powder primer must be applied. Color-keyed liquid primer is applied in many of the GM assembly plants in order to help achieve color harmony in difficult to spray areas or colors, while reducing the base coat film thickness. Color-specific liquid primer is applied in place of base coat in areas such as the trunk compartment, where finish appearance and weather resistance are not as critical. Color-keyed primer can also help to hide any chips or scratches that go down to the primer layer. Along with the environmental benefits achieved with single-color powder primer, then, multi-color powder primer would provide additional financial and customer satisfaction benefits.

The challenges to multi-color powder primer application extend from development through operation. One of the biggest burdens during development arises from the fact that each color powder coating will have a different material composition. GM has been working closely with powder manufacturers on the development of new powder primer colors to match existing liquid primer colors. For each color, performance properties such as gloss, as well as compatibility with all other sealers and coatings being used, must be validated. Finally, the coating process must be reviewed for each color, in case unique adjustments are required.

Operationally, the first challenge is to maintain the advantages of single-color powder coatings, the biggest being the reclaim capability that leads to minimal material waste. Originally, the belief was that for multi-color powder recycling, individual booths would be required to prevent cross-contamination between colors. Instead, a study performed by GM's Paint and Polymers Engineering (P&PE) department, showed that a single-booth application method can be used with multi-color powder recycling.⁴¹ The method utilizes all of the reclaimed powder of various colors by collecting it in a common reclaim collector system. The reclaimed powder is applied to the bodies as an initial coat, to attain a portion of the total film build required. The remainder of the film thickness is then applied as virgin paint over the multicolor reclaimed paint film. The reclaim and virgin applications occur in different zones of a single paint booth. The advantage of the method is that the final film surface of 100% virgin paint, with no cross-color contamination, prevents color from drifting with variations in build color mix. P&PE engineers determined that, based on typical vehicle surface area, film thickness, and paint transfer efficiency, all reclaimed material would be consumed as long as 0.6 to 0.7 mil of reclaimed material was used in the first coat. Given a theoretical total average film build target for powder primer of 1.8 mils for two coats, only 1.1 mil of film build would be available for the second coat. The P&PE study verified that even in light colors such as white, the second coat of

⁴¹ Murphy et al., P22

virgin powder would provide enough hiding of the underlayer to maintain its proper color characteristics.

The reclaim/virgin application method thus allows the reclaim system for single-color powder primer to be used with little modification for multi-color powder primer. The powder supply system, on the other hand, must be extended to include additional virgin color supply circuits. While color-keyed usually involves no more than three colors, color-specific involves one color for every topcoat color, often as many as ten. The required amount of supply equipment is proportional to the number of colors, which affects more than equipment cost. The physical floor space available in the paint booth, storage, and reclaim areas, constrains the addition of supply equipment. Also, the operating and maintenance costs will increase with additional equipment.

The second operational challenge for multi-color powder primer application is to perform as well as multi-color liquid primer. The application process must meet not only coating color and finish requirements, but also cycling requirements. As the P&PE Study points out:

The application of multicolor powder coatings, although done successfully in some industries, is very challenging for the automotive-body finishing shops because of strict requirements of high-volume throughput, quality finish, and full material use. The color-change time, which is usually 12 to 15 minutes for batch operations, such as the playground equipment manufacturer, has to be somewhere around 8 seconds for automotive applications.⁴²

Several technologies, including pinch- and rotary-valve-type equipment are available for powder color change for automotive-body finishing applications.⁴³ These technologies allow for multi-color application with an acceptable cycle time and without cross-contamination between jobs. Prior to a recent GM invention, however, these technologies have been primarily used with conventional powder primer supply equipment. As will be described in the following chapter, GM has addressed the supply and application of multi-color powder primer as a system, and has thus provided an outstanding solution for color change.

⁴² *Ibid.*, P19

⁴³ *Ibid.*, P19

Chapter 2: Innovation for the Application of Color Powder

The GM Canister Powder Paint Delivery System was designed to reduce the amount of supply equipment required for applying multiple colors of powder paint.

Typical single color powder paint delivery systems operate as follows:

In the powder storage room, virgin powder paint drops through a sieve into the virgin primary hopper. Reclaimed powder is cycled through a sieve into a reclaimed primary hopper, and a mixed primary hopper contains a mixture of virgin and reclaimed powder. The powder paint is distributed from the primary hoppers to feed hoppers located at booth level, using vacuum transport. Finally, venturi pumps deliver the powder paint from the feed hoppers to the applicators.

For colored powder paint application, color changers are available from equipment suppliers including ABB, Haden, Sames, and Behr. Placed before the applicators, these color changers serve the purpose of alternating between multiple colors of powder paint. The color changers receive powder from multiple feed hoppers and select which color is directed to the applicators. Yet, an additional delivery system, from primary hopper through feed hoppers, must be installed for each new color. Figure 2 illustrates how the amount of delivery equipment multiplies when spraying 10 colors rather than one, using conventional equipment with commercially available color changers.

The canister system combines existing color changer technology with a new invention, in order to minimize the amount of supply equipment required for multi-color powder paint application. As Figure 3 illustrates, the canister system eliminates the need for each applicator to have a dedicated feed hopper for each color, which also reduces the number of receivers and venturi pumps required. Instead, one primary hopper for each color supplies powder to all of the applicators, through the canister systems. The canister system thus substantially reduces the required number of pieces of equipment necessary for delivery. Additionally, alternative pump technology is currently being tested for use with the canister system. With the alternative pumps the canister system would decrease the amount of floor space taken up by color-specific powder primer equipment, to 65% of that required for the conventional delivery system.

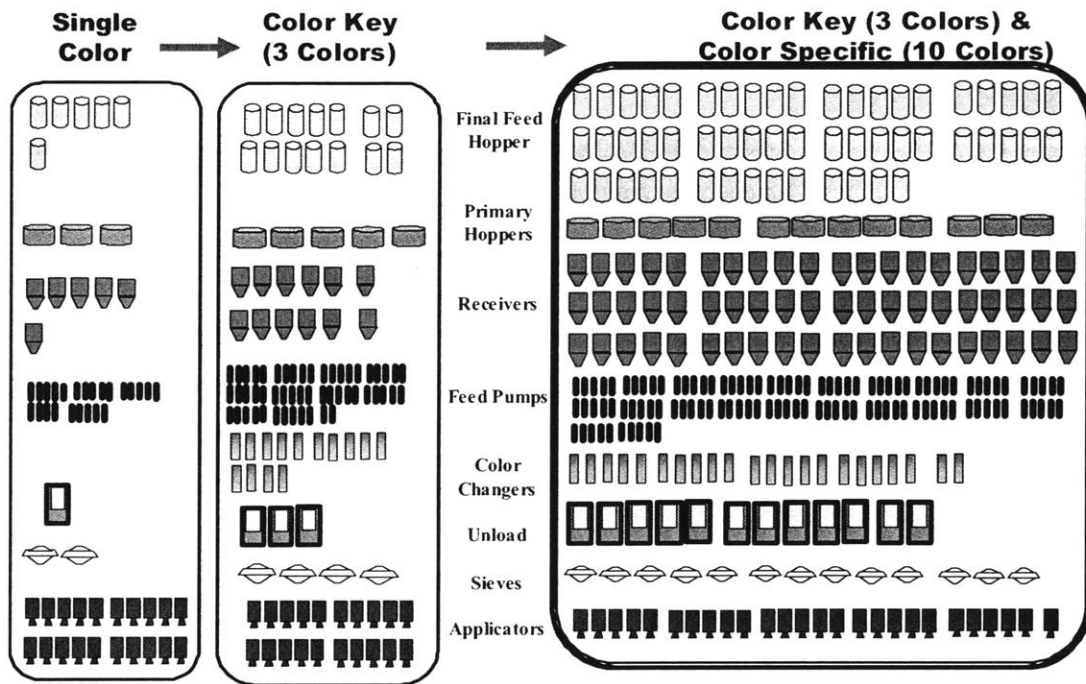


Figure 2: Conventional Delivery System Equipment Requirements, Single Color versus Multi-Color Powder Paint Application

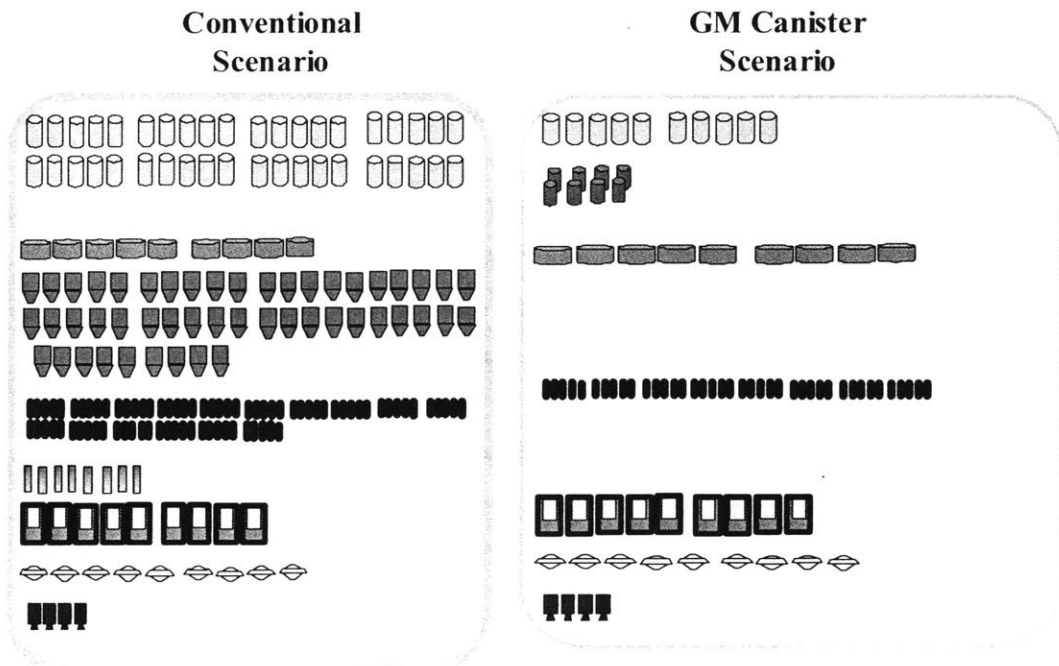


Figure 3: Delivery System Equipment Requirements for Color Specific Powder Paint, Conventional versus Canister System

2.1. MSQ Process

GM completes a standard Manufacturing System Qualification (MSQ) Process for any new technology or concept being considered for plant implementation. P&PE has traditionally used the process to evaluate new technology proposed by equipment suppliers; but for the canister system, MSQ has served as a guide for the development of GM's new technology. MSQ consists of four steps:

- Research – includes gathering background data on technology proposed by equipment suppliers, as well as generating concepts internally; may continue into Phase 0.0 Lab Validation
- Development – includes prototype feasibility demonstration followed by Phase 0.0 Lab Validation
- Production Testing – conducted for initial installation of new technology, includes validation at a beta-site plant: Phase 0.1 and Phase 0.2
- Production – conducted for subsequent installations of new technology (at this point considered established and added to the Validated Equipment list), includes validation in the plant: Phase 1 and Phase 2.

Affected documentation must also be updated appropriately. Figure 5 presents the MSQ process.

As illustrated, process development engineers and materials engineers interact a great deal during Research, Development, and Production Testing, while MSQ Phase 0 is being conducted:

- Phase 0.0, Lab Testing – conducted to demonstrate that the technology is appropriate for anticipated operating conditions
- Phase 0.1, Modular Build – conducted prior to production installation, to demonstrate that the equipment independently meets functional requirements (at this point, the technology has been developed into a modular component ready for system installation)
- Phase 0.2, Production Testing – conducted in Beta-Site plant, to demonstrate that the installed equipment performs to specifications in a production environment.

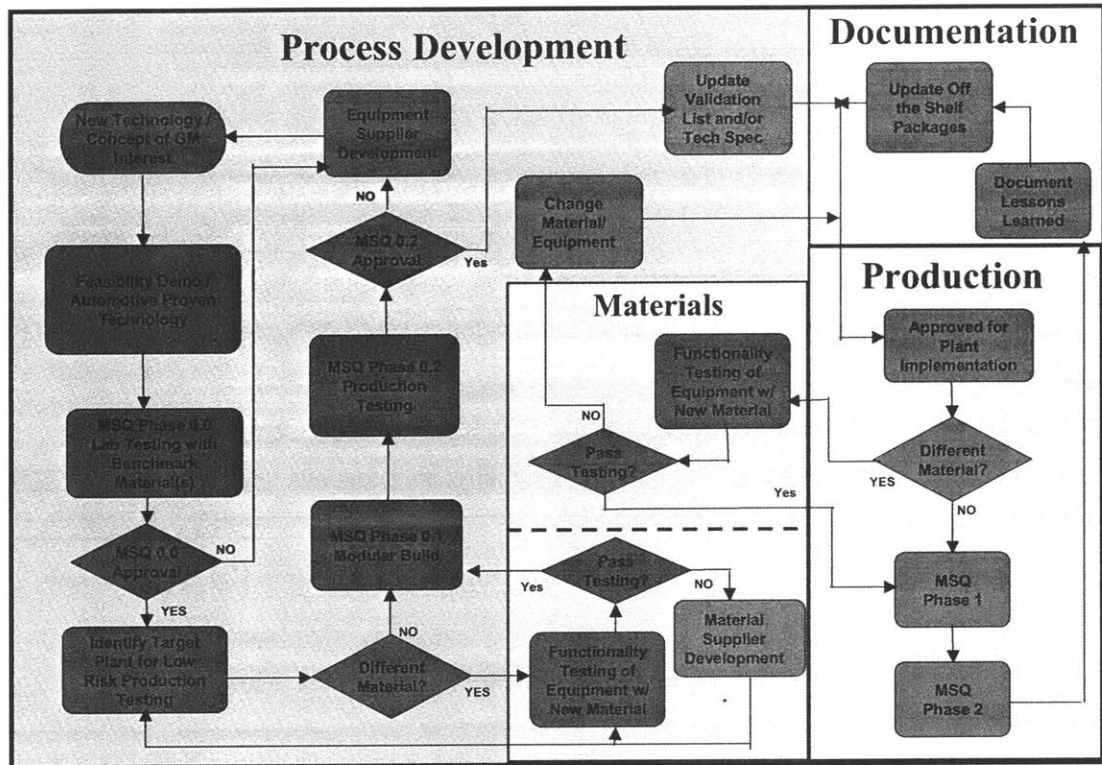


Figure 5: MSQ Process Flow Chart

Chapter 3: From Innovation to Implementation: Understanding the Industry

“At GM our focus is building vehicles, not paint application equipment. The key is to develop good ideas without entering a new market, in order to benefit not only GM, but also the industry and, most important, the environment.”

*Tom Meschievitz, Executive Director,
GM Paint and Polymers Engineering*

P&PE management recognized the potential value of the canister system concept proposed by P&PE Technology Development and Validation engineers, and provided the support necessary to take the internally generated idea from innovation to implementable technology. First they obtained upper management’s support for development of the invention. Next they identified a plant with management who shared P&PE’s goal, and would stand behind GM’s first color specific powder primer implementation. Finally, they had to decide on the best way to develop the invention, and then integrate it into a powder primer system, which would be manufactured and installed through the cooperation of multiple suppliers.

3.1. Path to Commercialization

In choosing a supplier partner for development of the canister system, P&PE recognized the value of combining its in-house knowledge of powder application with a supplier’s dedicated, hands-on engineering resources. This kind of partnership is common between electric utilities and power-class transformer manufacturers, and provides multiple benefits:

Alliances between manufacturers and utilities provide manufacturers some assurance of ongoing business preference and utilities with an agreed upon dedication of time and attention to design and manufacturing issues. Working alliances give both manufacturers and utilities incentive to work closely together to reduce costs and provide value by matching the equipment to the operating system in which it will function.⁴⁴

Four main factors drove P&PE’s supplier selection. Both speed and confidentiality were of the utmost importance. P&PE also required a supplier who would provide a high-quality product at a reasonable price. A high-quality design would result from a good working relationship between

⁴⁴ Koch, PE, William. “Power Transformer: From Specs to Installation.” *Electrial World*, New York: January/February, 2000, Vol. 214, Iss. 1, P18

P&PE engineers and the supplier. P&PE engineers, extremely familiar with paint shop operational and maintenance conditions, would lead the project, and the supplier's engineers would need to transfer P&PE input into an optimized design.

With these drivers in mind, P&PE selected SUPPLIER , to develop the color change system. A start-up in the paint application equipment industry, SUPPLIER supplied equipment and replacement parts to GM and other automotive companies. The interaction with P&PE engineers would allow SUPPLIER engineers to learn a great deal about color powder paint application, helping to further develop their powder technology. SUPPLIER would therefore provide quality engineering and manufacturing at a competitive price, and would give the project the attention demanded by GM.

GM's relationship with SUPPLIER is similar to BMW's relationship with Swiss design firm Ramseier Technologies.⁴⁵ BMW has partnered with the small design firm on multiple projects, for the development of innovative powder coating technology. The close relationship between Ramseier's engineers, highly skilled in design, and BMW's engineers, whose hands-on experience with paint processes leads them to recognize opportunities for improvement, has resulted in noteworthy inventions for coatings application. Unlike SUPPLIER, however, Ramseier completes little manufacturing. Instead, Ramseier licenses its technologies to larger manufacturers, including Dürr Industries, Inc., for development, manufacturing, and distribution. Because Ramseier has limited manufacturing capabilities, it focuses its engineering resources fully on the design of systems. Additionally, because Dürr will perform the distribution functions required for an invention to break even, Ramseier can dedicate its resources to developing technology for BMW. SUPPLIER, on the other hand, must balance its resources between equipment design and manufacturing, sales, and service.

The partnership between GM and SUPPLIER is largely based on a point made by Robert Gibbons, Distinguished Professor of Management at the Sloan School of Management: "when people interact over time, threats and promises concerning future behavior may influence current behavior." GM is more involved in the development than formally required, in order to ensure that the system will meet the plant's needs. SUPPLIER is dedicated to the development, because future business depends on its success.

Beyond the formal contract, then, the partnership relies on a relational contract, defined as an informal agreement or unwritten code of conduct that powerfully affects behavior, between the two companies. GM expects a quality product and responsive service from SUPPLIER, and in return SUPPLIER hopes for GM's continued business. According to Gibbons, relational

⁴⁵ <http://www.r-technologies.com/>

contracts help circumvent difficulties in formal contracting, by allowing the parties involved to utilize their detailed knowledge of their specific situation and to adapt to new information as it becomes available. Through cooperation, a better product can thus be developed, and both companies benefit from the relationship. Gibbons warns, though, that relational contracts must be self-enforcing agreements. Cooperation is prone to defection. For example, SUPPLIER may win a contract from another automotive manufacturer and be tempted to shift resources from GM's project to the new project, or GM may be tempted to use a less expensive supplier. In some circumstances, however, defection can be met with punishment. For instance, GM could decide to use another supplier if not satisfied with SUPPLIER's performance. A potential defector must weigh the present value of continued cooperation, against the short-term gain from defection followed by the long-term loss from punishment. Figure 8 illustrates how the extended loss from punishment can significantly outweigh the reward from defection.

As SUPPLIER aims to grow, its resources may be pulled toward multiple projects and customers. SUPPLIER's temptation to defect may increase. Therefore, although SUPPLIER is currently the best supplier for P&PE to partner with for development of the color change system, the relationship may change for future innovations. P&PE should be aware of these dynamics. More formal contracts, or efforts to increase the value of cooperation for SUPPLIER, may be required in order to keep up the productive partnership.

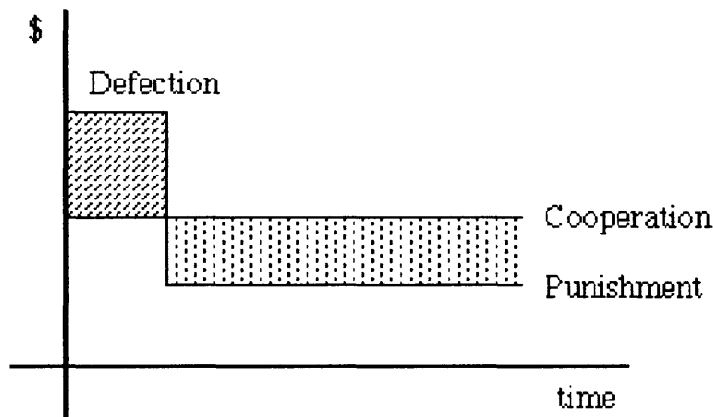


Figure 8: Value of Cooperation vs. Short-term Gain from Defection plus Long-term Punishment

The goal of GM's partnership with SUPPLIER, and BMW's partnership with Ramseier, is to enable development of useful powder paint application technology, through joint

development rather than in-house equipment design and manufacturing. Forward thinking companies like GM are taking innovation into account when making decisions, such as which components to include in new paint application systems. These kinds of decisions will also be impacted by the interests of suppliers competing in the paint application equipment industry.

3.2. Supply Chain Complications

Used to apply color-specific powder primer, the canister system would be part of a larger powder primer system, which in turn would be part of an entire brand new paint shop for the pilot plant. While coordination between areas of the paint shop would add complexity, the remainder of this chapter will concentrate on how implementation of the canister system would be completed through a powder primer paint booth project. The diagram in Figure 9 shows how different groups typically contribute to such a project.

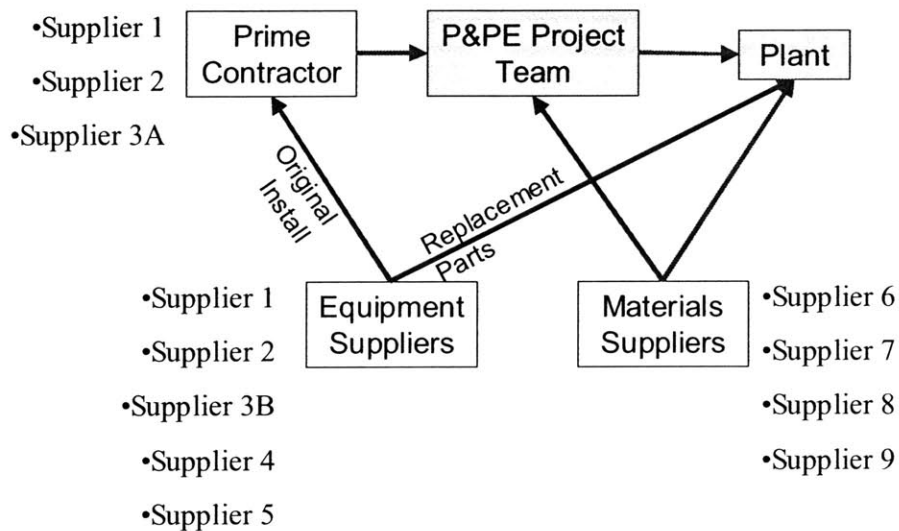


Figure 9: Supply Chain for Powder Primer Project

The supply chain seems straightforward. The plant is the customer of the P&PE Project Team. The project team employs a Prime Contractor to oversee system integration, which includes system design, installation, and commissioning. As appropriate, or as directed by the project team, the prime contractor subcontracts Equipment Suppliers to provide system components and subsystems.

This piece of the chain considers only the equipment itself. The plant must also receive materials for production. Currently, the Materials Suppliers provide paint directly to the plant, and also supply the project team with materials required for testing. In addition to providing specific formulations for the plant's needs, paint suppliers have taken on a larger service role during production, sometimes managing the entire painting process on a contract basis. Working

with the project team, materials suppliers also provide a variety of services, such as assisting in incorporating their paints into existing or new equipment, or advising on other types of equipment to use.⁴⁶

Upon further examination, the equipment supply chain has its own complications. For one, equipment suppliers provide replacement parts and maintenance services directly to the plant after their equipment is installed. An equipment supplier may therefore already have a relationship, good or bad, with the plant. Conversely, the equipment supplier's actions during a project may be influenced by its expected future business with the plant.

Most significant, and perhaps unique to the paint application equipment industry, are the connections between the prime contractors and the equipment suppliers. The industry is essentially composed of two types of players: a few equipment suppliers, represented by Suppliers 4 and 5 in the diagram; and system integrators who often also supply their own small equipment, represented by Suppliers 1 and 2. Sometimes a system integrator and equipment supplier, represented by Supplier 3A and Supplier 3B, may be sister companies within the same firm. As would be expected, conflicts of interest abound, especially given the high rivalry between suppliers competing for high-value capital projects. Service, research and development, and the ability to offer turn-key fully integrated systems are some notable areas of competition between suppliers.⁴⁷

P&PE is not the only GM division to recognize the benefits of having a single system integrator. A few years ago GM first employed Liebherr Gear Technology Co., of Saline, MI, for the integration of a gear manufacturing system.⁴⁸ GM assigned Liebherr the task of documenting the system and integrating automation. For more than 30 years, Liebherr has done this kind of work for manufacturers in Europe, from smaller plants to complete plants. Liebherr's value proposition is based on the fact that when more than one vendor is used and more than one department - plant engineering, automation engineering, process engineering – within the auto company is involved, there exists more opportunity for miscoordination and misinterpretation. Incomplete or miscommunication of information can affect the cost and function of a system as well as installation schedules. According to industry experience, manufacturers doing integration in-house can take one to six months longer than outsourcing to experienced integration companies. The schedule creep occurs because responsibility can be passed on when difficulties

⁴⁶ Bonifant, P210

⁴⁷ DeWitt, P37

⁴⁸ "System Integrator Helps GM Minimize its Time to Market." *Tooling & Production*, Solon: May 2000, Vol. 66, Iss. 2, P45

are encountered. To avoid all of these problems, manufacturers can assign a single entity, such as Liebherr, to be responsible for integration and operation of the system. The integrator will ensure that mechanical interfaces and electrical handshakes between each segment of the system are correct. Opportunities for cost savings within a system will also be more apparent to a single integrator.

Contracting system integration to a prime contractor does have drawbacks as well. Speaking of the installation of the paint shop at PSA Peugeot Citroen's Mulhouse Plant, Laurent Jeanningros, Responsible Service Maintenance, commented on the change from completing system integration in-house: "It is sometimes difficult to get the PSA installation technicians to fully commit. They are not always satisfied with their role as manager, rather than installation technicians. A feeling of frustration sometimes develops. This becomes more complex when the two parties have differences in interpretation of the specifications." These differences in interpretation can lead to what Professor Gibbons refers to as the "hold-up" problem. Hold-up occurs when the contracted party demands renegotiation, after investments have been made or new considerations have arisen, leading the parties to waste time bargaining. When the manufacturer performs system integration in-house, this kind of hold-up is avoided. Alternatively, formal contract terms can be used to prevent hold-up by the prime contractor. As Jeanningros points out, "The quality of the specification accompanying the order is crucial, as any change request is subject to arduous negotiation wherever this generates extra costs. It should also be borne in mind that at the end of the day the supplier can refuse." Gibbons cautions, however, that "using formal instruments (such as formal contracts or asset ownership) to stop one hold-up problem typically creates another." Often a better solution is to use informal instruments, namely relational contracts, in tandem with formal instruments. One relational contract, the promise of future business given good performance, has been discussed in the context of the GM/SUPPLIER partnership. Bonuses and incentive programs are other examples of informal instruments.

Contracting for system integration becomes more difficult with the subcontracting of equipment suppliers. Sharon Novak, Assistant Professor of Managerial Economics and Decision Sciences at the Kellogg School of Management, has written multiple papers on the subject of contracting in the automotive industry. In "Contracting, Directed Parts, and Complexity in Automotive Outsourcing Decisions," Novak examines the contracting process for interior

systems for luxury automobiles.⁴⁹ She notes that due to the additional coordination required by increased interaction of interior systems, interior development seems to be heading toward awarding the interior complete contract at once rather than by component or module. The awarding process, as outlined by Novak, is very similar to that used by P&PE to select a prime contractor:

Typically there will be around five to seven suppliers asked to bid on a given contract, based on rough technical requirements for the system to be developed. These requirements include: carryover parts from previous models, required or “directed” parts (parts, often made by others, that must be included in the design), and cost and performance milestones. Suppliers bidding on the contract provide the buyer with a quotation package that includes the detailed design, estimated engineering hours required to fulfill the contract, and the piece part price. Once all the quotations are received, the buyer chooses the least expensive contract that successfully meets the requirements. The typical timeline is that the supplier is paid largely based on the estimated engineering hours and develops the system.⁵⁰

Novak’s study is based on the assumption that the goal of the buyer in awarding the contract is to minimize costs given the product specifications, while the supplier’s objective is to maximize discounted expected profit.⁵¹ She focuses on two variables impacting program cost and supplier incentives for an interior complete contract: complexity and directed parts. The data shows that relative to simple, undirected systems, bid price is substantially increasing in both complexity and directed parts.⁵² This seems reasonable, considering that more complex projects require more work to complete to satisfaction and are thus more costly.⁵³ The data also shows, however, that the combination of high complexity and directed parts is associated with a lower bid price.⁵⁴ While one possible interpretation is that by directing parts, the buyer has reduced the work needed to complete the project; Novak suggests two other reasons for the reduction in supplier effort. She explains that with directed complex systems, suppliers may be less able to apply their previous systems knowledge to ensure product performance.⁵⁵ Additionally, the supplier may expect to be held less accountable, and thus put less effort into quality provision:

⁴⁹ Kilbanoff and Novak. “Contracting, Directed Parts, and Complexity in Automotive Outsourcing Decisions.” *Kellogg Graduate School of Engineering, Northwestern University*, Evanston, IL: 2003 (Version 2.1), P5

⁵⁰ *Ibid.*, P5&6

⁵¹ *Ibid.*, P9

⁵² *Ibid.*, P19

⁵³ *Ibid.*, P21

⁵⁴ *Ibid.*, P19

⁵⁵ *Ibid.*, P22

The presence of directed parts potentially shifts responsibility for system performance from the supplier to the buyer since the supplier may be able to claim ex-post that any performance failure was due to parts that the buyer chose. In non-complex systems, this effect is likely to be very small, for in such systems it is relatively easy to determine the cause of a given failure. In more complex systems, however, it is much more difficult to separate sources of failure within the system. As a result, the buyer is less able to hold the supplier to high levels of performance and system quality.⁵⁶

Overall, this means that a lower level of quality will be delivered and accepted for such contracts, and the impact may be to shift the cost of upfront quality control to resulting higher failure rates.⁵⁷ The implication for managers is that highly complex, directed systems should be analyzed in terms of overall program cost/performance rather than upfront bid.⁵⁸

Novak's findings are extremely pertinent to P&PE. The powder primer paint booth is a very complex system, and P&PE is directing the prime contractor to include the canister system for color-specific application. Yet, Novak's study does not address the relationships that may exist between suppliers, as they do in the paint application equipment industry. The system integrator for the powder primer paint booth will not be independent. Rather than taking direction from P&PE, the prime contractor may prefer to supply its own equipment or purchase equipment from a sister company. If P&PE can accept the prime contractor's recommended equipment, the non-directed, complex system may actually have a lower price. While economies of scope would affect the price, the supplier's marketing and sales strategy would determine whether the price would be significantly discounted; for example, to put a new equipment design into production. If P&PE is hesitant about using the recommended equipment, the prime contractor may use hold-up to influence P&PE's decision. The hold-up threat will not succeed, however, in the case of the canister system. P&PE has chosen one supplier to develop and manufacture the system and is directing the prime contractor. Given the complex, directed system, P&PE should be aware of the prime contractor's motivations.

Multiple problems can occur with what Jerold Zimmerman, author of Accounting for Decision Making and Control, refers to as "goal incongruence" between a buyer and supplier.⁵⁹ Zimmerman explains that when principals, such as the project team, hire agents, such as the

⁵⁶ *Ibid.*, P15

⁵⁷ *Ibid.*, P23

⁵⁸ *Ibid.*, P31&32

⁵⁹ Zimmerman, Jerold L. Accounting for Decision Making and Control, Fourth Edition. McGraw-Hill Irwin, New York, NY, 2003, P162

prime contractor, the agency problem often arises. Agency costs result from agents pursuing their own interests to the detriment of the principal's interest.⁶⁰ Furthermore, if the agent expects to leave the organization before the principal, the agent will tend to focus on short-run actions. Because the principal's interests are long-term, this leads to the horizon problem.⁶¹ The P&PE project team may be faced with both agency and horizon problems in its relationship with the prime contractor, because the contractor will of course have its own interests, and will not be involved with long-term operation.

One way to control the agent's performance is to limit the agent's discretion in making decisions, which can also potentially reduce the resources consumed by parties politicking and trying to influence decisions.⁶² Directing parts would be an example of limiting the contractor's decision-making freedom, but as discussed, consequences can be varied. Alternatively, responsibility accounting can be used to better align the interests of the agent with those of the principal. When applied to groups within an organization, responsibility accounting seeks to identify the objectives of each part of the organization and then to develop performance measures that report the achievement of those objectives.⁶³ For the powder primer paint booth, the responsibility of the prime contractor is to efficiently integrate the system. Total system cost is a possible performance measure. Zimmerman recommends against applying the controllability principle with responsibility accounting.⁶⁴ The controllability principle, by which managers are held responsible only for decisions over which they have authority, does not give incentive to take actions which can affect the consequences of an uncontrollable event. In the case of the powder primer paint booth, the prime contractor cannot control the weather. Measuring on total cost, however, gives the prime contractor incentive to take actions to complete the external facility before the winter season and to minimize the impact that a schedule delay due to weather would have on the paint booth project.

Zimmerman warns that no performance measurement and reward system works perfectly.⁶⁵ In this case, total system cost is a short-term measure, and thus does not solve the horizon problem. Additionally, Zimmerman recognizes that non-accounting measures are often more timely than accounting measures.⁶⁶ Non-financial data such as weekly number of corrective change orders would provide a periodic measure for the prime contractor's performance.

⁶⁰ *Ibid.*, P159

⁶¹ *Ibid.*, P160

⁶² *Ibid.*, P168

⁶³ *Ibid.*, P207

⁶⁴ *Ibid.*, P208&209

⁶⁵ *Ibid.*, P210

⁶⁶ *Ibid.*, P176

Although responsibility accounting provides financial incentives for suppliers, it does not specify how tasks must be completed in order for the project to be successful. Critical path planning is one method for scheduling and assigning accountability for these tasks. Focusing on the critical path – the longest sequence of tasks required for the project – critical path planning defines who is responsible for which tasks when, and documents the impact of each task on subsequent tasks and parallel sequences. Another method P&PE should consider, critical chain project management (CCPM), takes the planning process one step further. As Lawrence Leach, the principle of Quality Systems, a management consulting firm, explains,

To perform any task on a project, two things are necessary: the task from a predecessor and the resource to perform the task... The definition of the critical path does not explicitly address the potential resource constraint... The critical chain is simply ‘the sequence of dependent events that prevents the project from completing in a shorter interval. Resource dependencies determine the critical chain as much as do task dependencies.’⁶⁷

CCPM avoids multi-tasking of resources, and accounts for common cause variation that prevents individual tasks from completing on-schedule. The first goal is achieved by removing resource conflicts, and more importantly, by including resource buffers in the plan to ensure that critical chain resources are available when needed. The second goal is achieved by developing the plan using average estimates of task duration (i.e., with no contingency), and aggregating uncertainty into a project buffer at the end of the critical chain. The project manager expects 50% of tasks to overrun, while the others are completed in less time than anticipated. Additionally, feeding buffers are placed at the end of each path that feeds the critical chain. Resource, project, and feeding buffers are illustrated on the sample critical chain project plan shown in Figure 10.

⁶⁷ Leach, Lawrence P. Critical Chain Project Management. *Artech House, Inc.*, Norwood, MA, 2000, Section 4.2.1.

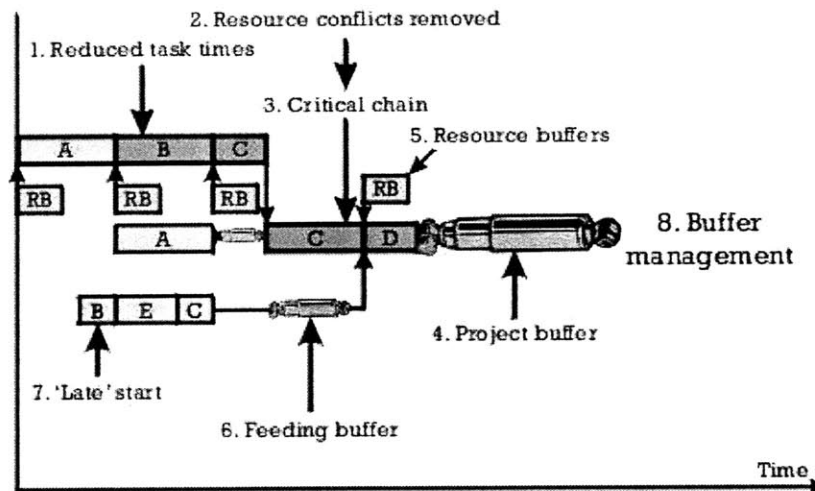


Figure 10: Key Features of Critical Chain Project Plan⁶⁸

Leach summarizes:

Critical chain project plans provide dates only for the start of task chains and the end of the project buffer. For the rest of the project, the plan provides approximate start times and estimated task duration. Critical chain project managers do not criticize performers who overrun estimated task durations, as long as the resource (a) started the task as soon as they had the input, (b) worked 100% on the task (no multitasking), and (c) passed on the task output as soon as it was completed.⁶⁹

The mentality is very different for CCPM than for critical path planning. For this reason, Leach recommends not even publishing or discussing individual task start and complete dates. Leach also recommends against starting early on a task, because the resources may be better used elsewhere, and feeding buffers provide needed cushion.

Involving suppliers in a new process such as CCPM would be challenging, but would ensure that the responsibilities of each supplier are clear. CCPM would provide the structure for the project, while responsibility accounting would provide incentives for the contractors. Managing suppliers through development and installation, however, is not the only job for the project team. P&PE must also help prepare the plant for the transfer of the canister system technology from the central engineering organization to the production facility.

⁶⁸ Leach, Figure 4.1

⁶⁹ Leach, Section 4.2.4.1

Chapter 4: Technology Transfer: Criteria for Success

Building confidence is critical to the success of GM's Paint and Polymers Engineering Department, as P&PE leads the introduction of low-emission paint technology into the company's production facilities. Thus, the primary goal of P&PE is to prove that innovative paint application equipment, such as the canister system, is technically satisfactory for the plants. Technical preparation alone, however, does not guarantee trouble-free implementation. P&PE leadership must continue to demonstrate commitment to economically feasible, environment-friendly paint technologies like the canister system. Most importantly, P&PE must continue to disseminate a pioneering culture, through the project team and plant management, to each plant employee. Personal pride shared by all involved will lead to success during initial implementation and beyond.

4.1. Validation of System to meet Technical Requirements

The technical challenge is not unique to P&PE: to develop a manufacturing system that can be installed in a plant and put into operation without delaying production. P&PE's unique approach, however, was to establish the Manufacturing System Qualifications Process, outlining how all paint application equipment must be validated before and during installation in a plant.

4.1.1. Goals of MSQ Process

MSQ does not define specific criteria for each new system, but provides a framework for exploring the capabilities and characteristics of new technology. As described previously, MSQ is used as a tool for development, and ultimately for plant installation.

The first goal of MSQ is to guarantee functionality: that the system does what it is supposed to do, over a range of operating conditions. Assembling the system and testing its functions in the lab gives promise that the system will perform the same functions in the plant. It also allows for debugging before installation at the plant, where staff may not have the skills, tools, capacity, or time to trouble-shoot.⁷⁰ The functionality testing performed during MSQ is meant to avoid extensive in-the-field adjustments, and to meet the plant's expectation that brand-new equipment will work.

⁷⁰ "System Integrator Helps GM Minimize its Time to Market." *Tooling & Production*, Solon: May 2000, Vol. 66, Iss. 2, P45

The second goal of MSQ is to determine the reliability and maintainability of the system. Durability testing assures that the equipment will withstand the high cycling requirements of the plant. In conjunction with durability testing, a Failure Mode and Effects Analysis is performed. Both are used to develop equipment maintenance schedules that will prevent unexpected downtime. Also, durability testing provides an opportunity to begin defining operating and maintenance procedures.

Finally, the functional and reliability characteristics of a system, determined through MSQ, can be used to predict the costs for operating and maintaining the system. These include fixed, variable, and life-cycle costs of the production system.

As a structured process adopted throughout P&PE, MSQ has the additional benefit of sharing best practices between plants. MSQ ensures that key information about each system is documented. For instance, statistically designed experiments are frequently used in MSQ, to determine an optimum operating window and documented evidence for the relationships between process variables and response variables. The experiment results can be distributed to operators so that all shifts are aware of acceptable operating conditions. Furthermore, not only the first installation, but also all subsequent installations are included in the MSQ process. This formal link between all projects involving a particular system allows for better incorporation of lessons-learned. As evidence, after Shreveport powder application equipment had experienced longer-term operation, and system deficiencies had been discovered, modifications were made to existing facilities; and changes in engineering for systems that were not yet fully constructed were initiated and implemented.⁷¹

4.1.2. Challenges to MSQ Process

Can a combination of functionality and durability tests be designed to accurately represent the real-world conditions expected for a new technology?

The MSQ Process begins to address this question by taking a systems approach to testing. It is not enough to test an applicator alone. What matters is the overall performance, operating cost, quality and system efficiency of the totally integrated powder coating system, of which the applicator is only a part. MSQ Phase 0 testing therefore proceeds from components to integrated system. Much of the component testing is actually conducted by the supplier, independent of MSQ. According to Rick Ostin, Director of R&D of Technology at Behr Systems, basic mechanical tests addressing robustness, and operational characteristics such as air consumption,

⁷¹ Lis and Messerly, P7

are completed for each new applicator. What he refers to as process testing, however, is always changing, depending on variables including type of coating, brand of coating, whether robots are being used, etc. Integrated testing must therefore be completed jointly with manufacturers like GM.

As mentioned earlier, other areas of GM are also recognizing the value of integrating and running systems prior to installation. Helmut Link of Liebherr Gear Technology Co., commented on GM's new approach for the gear manufacturing system:

They didn't buy various machines from a handful of vendors, run off each one at a different place, and assemble them into a system for the first time on the floor of the factory, only to find out that the machines do not fit and work seamlessly together.

Instead, machines... were brought to the Liebherr floor, assembled, connected with automation, and run off as an integrated system... The project was completed in five months – about half the time a similar system would normally require, according to GM engineers.⁷²

The next challenge is to account for the transition from a controlled laboratory to a high-speed production environment. DaimlerChrysler AG's approach has been to simulate the plant environment, by making the largest R&D investment in Canadian history, including a 45,000 sq-ft coatings laboratory in Windsor, Ontario.⁷³ The Automotive Coatings Research Facility is the only one of its kind in the world, replicating a full-scale paint shop. It will never coat a vehicle for sale, but it will test materials, processes and equipment including spray guns and ovens. GM's solution is the MSQ Process, which includes both lab and production testing. After lab testing (MSQ 0.0) is completed, the supplier builds a modular unit (MSQ 0.1). The modularity provides an interface to mate with existing systems, so that the new technology can be installed in an operational paint booth relatively quickly and easily. MSQ Phase 0.2 testing then takes place at a beta-site plant, a low-risk production environment.

With beta-site testing and full-scale lab facilities, however, all details cannot be accurately represented. Ultimately, the site-specific requirements for each plant must be considered. Slight variations in paint booth configuration may cause differences in downdraft, faster line speeds may require adjustment of a robot profile, different combinations of applicators may change the film build distribution, and so on. For this reason, the MSQ Process includes Phase 1 and Phase 2 testing. Phases 1 and 2 mirror Phases 0.1 and 0.2, but with modifications as

⁷² "System Integrator Helps GM Minimize its Time to Market." *Tooling & Production*, Solon: May 2000, Vol. 66, Iss. 2, P45

⁷³ "DC to Test Advanced Paint Systems in Canada." *WardsAuto.com*, September 25, 2000, P1

required to reflect conditions unique to each new installation. Completing MSQ Phase 0 should provide an understanding of the system such that Phases 1 and 2 proceed without difficulty.

4.1.3. Benchmarking: Pharmaceutical Industry and Medical Device Industry

MSQ is more than a collection of functionality and durability testing. The MSQ Process provides a standard approach for validating systems, yet allows flexibility to account for unique system characteristics. The key to MSQ's success is the different phases in which both operational and reliability tests are conducted. In this respect, the MSQ Process can be compared to validation procedures used in an industry where product quality is of even greater importance than for automotive coatings.

In the pharmaceutical industry and medical device industry, manufacturing quality can be a matter of life or death. The Food and Drug Administration has therefore developed a current good manufacturing practice (cGMP) program for pharmaceuticals, and a strict Quality System Regulation for medical devices as part of its Code of Federal Regulations. Consider first medical devices, which seem more comparable to automobiles, in that many are electro-mechanical and have high production rates. Section 820.30 of the Code of Federal Regulations focuses on design requirements for medical devices, but also includes the following paragraph, emphasizing the difficulty of designing for manufacturing:

- (h) Design transfer. Each manufacturer shall establish and maintain procedures to ensure that the device design is correctly translated into production specifications.⁷⁴

Section 820.75 defines process validation requirements:

- (a) Where the results of a process cannot be fully verified by subsequent inspection and test, the process shall be validated with a high degree of assurance and approved according to established procedures...
- (b) Each manufacturer shall establish and maintain procedures for monitoring and control of process parameters for validated processes to ensure that the specified requirements continue to be met...
- (c) When changes or process deviations occur, the manufacturer shall review and evaluate the process and perform revalidation where appropriate...⁷⁵

⁷⁴ Code of Federal Regulations, Title 21 - Food and Drugs, Part 820 - Quality System Regulation. April 1, 2003, Section 820.30.

⁷⁵ *Ibid.*, Section 820.75.

Companies can obtain guidance for meeting these high-level requirements in the FDA Quality System Manual.⁷⁶ The manual describes three phases of validation: Installation and Operation Qualification (IQ/OQ), Process Performance Qualification, and Product Qualification.

During IQ/OQ, process equipment “should be installed, reviewed, calibrated, challenged, and evaluated to ensure that it is capable of operating within established limits and tolerances as well as throughout all anticipated operating ranges.” IQ/OQ is very similar to MSQ Phase 0.0. Some of the objectives include determining installation requirements, establishing any needed environmental controls and procedures, and determining calibration, cleaning, maintenance, adjustment, and expected repair requirements. Although qualification runs may be performed at the equipment fabricators’ facilities, the Quality System Manual stresses that it is usually insufficient to rely solely upon the equipment supplier; the device manufacturer is ultimately responsible for deciding whether the equipment is suitable for use.

The purpose of Process Performance Qualification is to “rigorously test the process to determine whether it is capable of consistently producing an output or in-process or finished devices which meet specifications.” Much like MSQ Phases 0.1 and 1, Process Performance Qualification includes simulating conditions that will be encountered during actual production. Standard operating procedures are followed, and repeated enough times to assure that the results are meaningful and consistent. Data is analyzed to determine whether a process is operating in a state of control.

Lastly, Product Performance Qualification demonstrates that “the process has not adversely affected the finished product and that the product meets its predetermined specifications and quality attributes.” The Quality System Manual stipulates:

Products used for design validation should be manufactured using the same production equipment, methods and procedures that will be used in routine production. Otherwise, the product used for design validation may not be representative of production units and cannot be used as evidence that the manufacturing process will produce a product that meets predetermined specifications and quality attributes.

Taking place in the plant with actual production equipment, MSQ Phases 0.2 and 2 follow the same logic.

The phases of GM’s MSQ Process appear to mirror the qualifications required by the FDA Quality System Regulation, as summarized in Figure 11.

⁷⁶ Quality System Manual. U.S. Food and Drug Administration, Department of Health and Human Services, Center for Devices and Radiological Health, 1997.

FDA Qualification	Task/Function	Corresponding MSQ Phase
Installation and Operation (IQ/OQ)	Ensure that process equipment is capable of operating within established limits and tolerances, and throughout all anticipated operating ranges	0.0
Process Performance	Determine consistency of process, simulating actual production conditions	0.1 &1
Product	Demonstrate that product meets specifications, using the same production equipment, methods and procedures that will be used in routine production	0.2 &2

Figure 11: Comparison of MSQ Phases with Qualifications required by the FDA Quality System Regulation

Unfortunately, these extremely thorough processes also share some drawbacks. In a presentation entitled “FDA Regulation of Drug Quality: New Challenges,” Janet Woodcock, MD, Director of the FDA Center for Drug Evaluation and Research, highlighted two unintended consequences of the validation requirements for drug manufacturing companies:

- Manufacturing process efficiency low
- Innovation, modernization and adoption of new technologies slowed⁷⁷

Woodcock elaborates that an emphasis on getting product out discourages process improvement. Due to time pressures, a manufacturing system that has passed product performance qualification will continue to be used, even if it may not be the most efficient means of production. Not only improvements to existing systems, but also development of innovative systems, are discouraged by the high costs of validation. GM experiences these problems with the MSQ Process as well; perhaps to an even greater extent, because drivers for medical device (safety) and automotive coatings (customer satisfaction) validation are different. While quality is demanding for both, with medical devices quality is an issue of life or death. The medical device suppliers recognize that even though the cost is high, validation will prevent higher safety-related costs that could occur later. In order to decrease costs, particularly the burden on the FDA to regulate all of the manufacturing companies, the FDA is focusing on risk assessment as a means to better define the

⁷⁷ Woodcock, MD, Janet. “FDA Regulation of Drug Quality: New Challenges.” Presentation Slides, April 9, 2002, Slide4

focus of validation. P&PE must similarly consider not only the cost of performing validation, but also the time required for process development engineers to monitor suppliers.

4.1.4. Recommendations

At the highest level, the goal of MSQ is to mitigate risk of a delay in production during implementation of new paint application technology. Having a backup is another means of reducing the risk. For example, PSA Peugeot Citroen's Mulhouse Plant continued to operate its old paint shop while ramping up production in its new powder-primer-capable paint shop.⁷⁸ Strategic scheduling can also decrease the risk of impacting production. At Shreveport, GM debugged the powder system during the Christmas downtime to run on the existing vehicle for January 1993 start-up.⁷⁹ The plant then shut down again in April 1993 for a change over and start-up of a new product in June of 1993. This timing allowed the organization to adjust to one change at a time, evaluating and modifying the new powder system under a production environment, prior to introduction of the new model.

All of these risk mitigation methods have financial impacts. A risk-benefit analysis must consider the operational costs of keeping a back-up production line running, the costs associated with mobilizing a commissioning team twice instead of once, and the substantial costs of lab testing. How can these costs be minimized?

Focusing on the MSQ Process, testing conducted by suppliers could be better coordinated. Final equipment costs reflect the testing costs incurred by suppliers. If the automobile manufacturers were to establish industry standard tests, suppliers could complete these once and then spread the costs over all units sold. When asked what percentage of testing completed for a single applicator design is recognized by more than one customer, Rick Ostin of Behr Systems replied, "less than 50%." The remaining testing is conducted to fulfill each manufacturer's individual requirements. While 100% overlap may not be possible, increasing the number of common tests would decrease costs. The power industry has successfully adopted testing standards, simplifying specifications to reduce cost and speed up delivery.⁸⁰ ANSI defines standard tests for power-class transformers, and electric utilities must identify any additional optional tests they want performed by the transformer manufacturer. Convincing automobile manufacturers to agree on standard testing procedures may be too difficult, but Ostin points out that even companies within global corporations could be better aligned. He described

⁷⁸ Diem, P1

⁷⁹ Lis and Messerly, P2

⁸⁰ Koch, PE, P18

how validation of an applicator for use by GM in North America and Opel in Europe was greatly simplified, because GM has been successful at developing global standards for paint processes.

On the flip side, as discussed in the preceding chapter, the innovative paint systems being worked on today involve multiple suppliers. These suppliers must cooperate, in order for system validation, as well as development and implementation as a whole, to be a success.

4.2. Preparation of Plant to meet ‘Soft-side’ Requirements

Thus far this thesis has focused on the work that the P&PE Department, utilizing suppliers, must complete in order to prepare a new paint application system for installation. Implementation, however, includes adoption of the new technology after installation. It will involve multiple groups within P&PE, as well as plant management, engineering, and personnel. The organizational processes for P&PE and the pilot Plant, individually and as they interact, will play a large role in the implementation’s success.

4.2.1. Organizational Factors

John S. Carroll, Professor at the Sloan School of Management, teaches an approach to organizational analysis based on The Three Lenses.⁸¹ The Three Lenses model can be used as a tool for analyzing how a change initiative will impact an organization. Examining the organization through the strategic, political, and cultural lenses, leadership can identify detrimental misalignments and barriers to communication. Sometimes small efforts can have a large impact on attitudes, interests, and relationships, and thus enable change. Additionally, the following analysis for installation of the canister system at the pilot plant reveals organizational strengths that will ease implementation.

4.2.1.1. Strategic Design

Figure 12 illustrates the formal links between P&PE and the plants, with P&PE resources highlighted in a darker shade.

The Liaison Engineer is assigned to two or three plants, and is responsible for visiting the plants regularly. The Liaison Engineer keeps P&PE informed of each plant’s operating and maintenance procedures, any equipment and quality issues, and requirements for future production; and informs the plant of any improved procedures, as well as development work going on at P&PE. Maintaining continual contact with the plants, the Liaison Engineer is an excellent linking mechanism and source for understanding the cultural and political idiosyncrasies of each plant.

The Resident Engineer is located at the plant to oversee smaller capital projects, such as the installation of new applicators in a paint booth. The Resident Engineer serves as a buffer

⁸¹ Carroll, John S. “Introduction to Organizational Analysis: The Three Lenses.” *Sloan Management Review* (MIT Sloan School of Management), 2001.

between the plant and P&PE's centralized resources for projects. For larger capital projects, the Resident Engineer is part of a project team. For example, the canister system will be installed as part of construction of an entire new paint shop. A Project Manager leads the project team, which can include any number of coordinators, engineers, and plant representatives, depending on the particular project.

Supporting the project team, Technology Development and Validation (TD&V) engineers provide technical leadership for first-time installation of new technology, while Process engineers give technical guidance for subsequent installations. Facilities engineers and Materials Engineers are involved with all installations, as well as Subject Matter Experts (SME). All of these groups within P&PE provide on-site support to the plants as needed.

Strategically, the P&PE organizational design appears to provide multiple means of sharing information, and to assign clear roles for each group to contribute to the organization's goal. The formal structure should thus facilitate transferring technology to the plant.

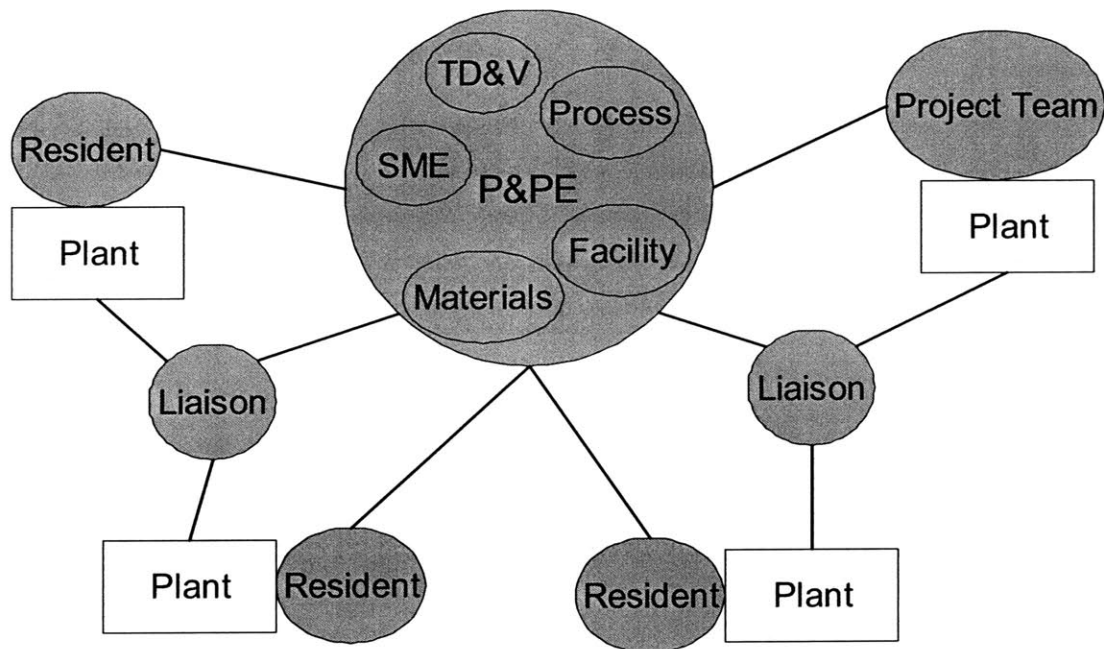


Figure 12: Interfaces between P&PE and the Plant

On the receiving end, the project team includes representatives from the plant. One benefit is that the plant is more actively involved in the planning process, providing useful input regarding operational and maintenance requirements. Conversely, the plant representatives can keep plant management updated on the project's progress. Also, as they learn the details of the

system design, the plant representatives can gradually expose the plant staff, which will ultimately be responsible for operation and maintenance, to the new technology far in advance of the installation.

4.2.1.2. Political Lens

Observing an organization through the political lens reveals where power struggles may occur, as stakeholders use their individual sources of power to pursue their own interests. Managers should be aware of how such friction can arise. In the case of the canister system, political factors are minor compared to the cultural issues involved with implementation.

4.2.1.3. Cultural Lens

Cultural issues abound when implementing new technology at an established plant. GM Leadership can capitalize, however, on the positive symbolism of the canister system. For P&PE, the project represents cutting-edge engineering, and making GM the most environmentally advanced coatings applier in the automotive industry. Executive Director Tom Meschievitz has done an impressive job of instilling pride in his organization, especially through quarterly Department Meetings that highlight key achievements and projects, and emphasize his commitment to priorities including safety and quality.

For the pilot plant, the new paint shop is associated with the launch of a new product. With the new product, cultural changes will be introduced throughout the plant. In the paint shop, this will involve breaking habits that have formed as the workforce has dealt with aged equipment and a very demanding production schedule. The strict cleanliness requirements for the powder system will call for all employees to take responsibility for the work area, or quality will be impacted. Great team effort will also be necessary to understand the operational and maintenance requirements of the complicated new system. Cleanliness, self-motivation, and cooperation are important values for the plant culture. The focus at the plant is to motivate all members of the paint shop staff to have pride, in their equipment and the work they accomplish as a team.

It will be easier to have pride in all brand-new equipment, in comparison to the equipment currently in the paint shop. With age, the existing paint equipment has become more difficult to maintain, especially given the high production rate. The plant operates three shifts per day, Monday through Friday, with maintenance being performed only during breaks and lunch, and on the weekends. With priority placed on keeping up production, the maintenance process in

the paint shop has become reactive. The upcoming installation provides an opportunity to establish proactive goals, emphasizing preventive maintenance and continuous improvement in order to make the most of the new assets.

The most recent paint application equipment was installed in 1987, for liquid basecoat. Plant electrical engineers can easily trouble-shoot the very basic automation electronics, while the oscillation of the applicators is mostly controlled mechanically with crankshafts. Fully automated painting will be new for the plant. The electronic controls will be much more sophisticated, and the interactions between subsystems will dramatically complicate trouble-shooting. With the complexity of automated paint processes, the plant culture will need to place even greater value on technical and leadership skills. Merit and expertise will be the best qualifications for positions in the paint shop. Additionally, Process Engineers, who can work with electrical and mechanical engineers to address system issues, should be appreciated for their leadership during trouble-shooting and continuous improvement work.

4.2.2. External Reference: PSA Peugeot Citroen's Mulhouse Plant

PSA Peugeot Citroen's Mulhouse Plant serves as a reference for the GM plant receiving the canister system. PSA Peugeot Citroen is the first automotive plant in Europe to apply multi-color powder primer. Although the technology used by the two companies is very different, this section compares the strategic design for the multi-color powder paint primer implementations at PSA and GM.

As Laurent Jeanningros, Responsable Service Maintenance, described, the installation of the new paint shop at the Mulhouse Plant involved two main groups within PSA's Paints technical area:

ATI, ("l'amont technico-industriel") refers to the department that conducts the preliminary technical and industrial activities required for new vehicle launches or for high volume industrial projects. ATI designates the paint shop design modifications to be implemented for the launch of new vehicles, for technical upgrades, for requirements expressed by DIFA (profitability, environmental standards etc.), or for the launch of new paint shops such as at Mulhouse. DIFA refers to the Industrialisation and Manufacturing Division. The manufacturing plants come under the responsibility of DIFA. Each department is in charge of a function within the company, for which it has total responsibility: DIFA's role is to produce vehicles, and ATI's role is to design new vehicles and manufacturing systems. Each department has its own central organization which defines the strategy in that particular

sphere. A transversal network at PSA links up the two divisions at all levels right down to the individual plants.

In a paint plant industrial project, DIFA is the project owner, the 'client', and ATI is the 'contractor'. Both ATI and DIFA appoint a project manager to what is known as the project platform, the method of organising the design, production, and management phases of a project. The platform includes staff from ATI and DIFA, plus the suppliers, with the number of representatives and the skill levels varying for the different phases of the project. DIFA provides resources from the involved plant to the project platform for participation in the project. Project resources from different technical areas are also drawn together in order to facilitate management of the various interfaces.

PSA Peugeot Citroen's strategic design is illustrated in Figure 13, with representatives to the project platform highlighted in a darker shade. At the department level, the groups performing vehicle engineering and process engineering are both part of ATI. Vehicle design and manufacturing process design should therefore be closely linked, while DIFA focuses on plant operations. In contrast, P&PE, responsible for manufacturing process design at GM, falls under GM's manufacturing organization along with the plants, while P&PE representatives interface with vehicle design engineers. Peugeot's project platform is similar to P&PE's project team, in that it includes representatives from both the engineering group and the plant. One difference is that DIFA, the manufacturing organization, dedicates a project manager to the platform; while P&PE works directly with individual plants. Support from DIFA ensures that best practices and lessons learned with any new system will be shared with the other plants.

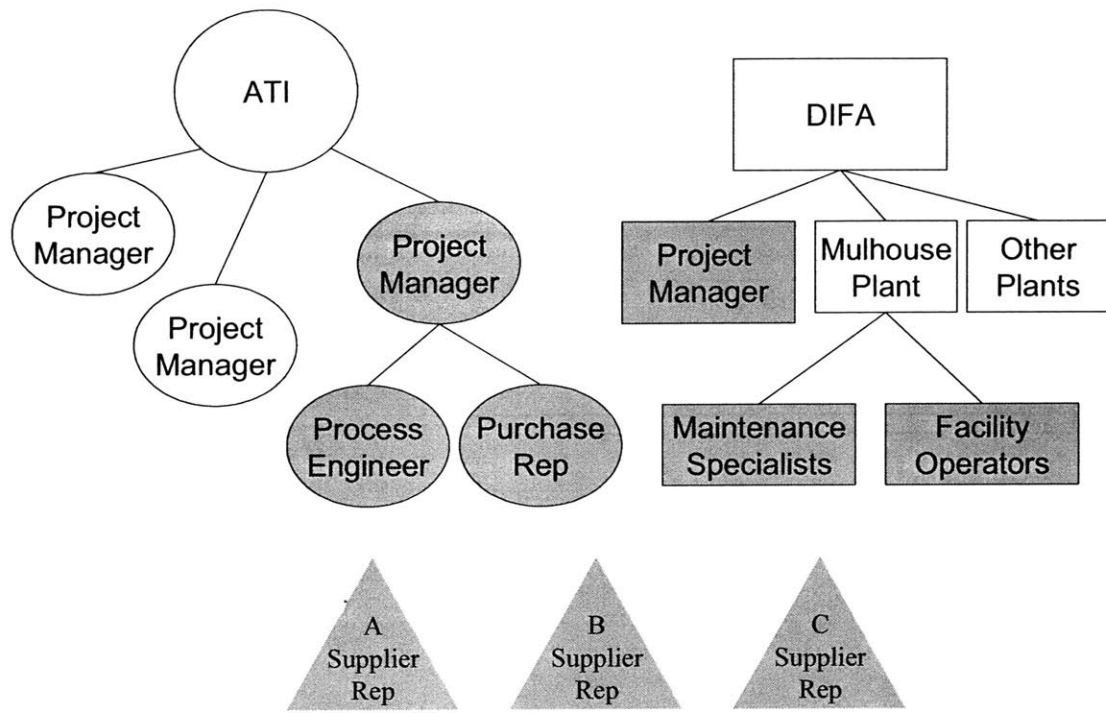


Figure 13: PSA Peugeot Paints, Project Platform

According to Jeanningros, success depends on the plant being fully involved. The project platform must include representatives from all parties involved, such as maintenance specialists, facility operators, and plant management. Most important, the plant must be involved in the project as early as possible, from the design phase onwards (no matter how small the resources if the phase does not require strong involvement).

4.2.3. Internal Benchmarking: Past implementations of new paint technology at GM

Lessons of what to do can be learned from GM's previous installations of paint application systems. For example, innovative application equipment for waterborne liquid topcoat was recently installed at one of GM's assembly plants. As Project Manager Bill Frank described, a few factors greatly contributed to the success of the installation. First, the culture at the plant was relatively adaptive to change. Producing high-mix, low-volume vehicle models, the plant was accustomed to adjusting to new product requirements. Adopting a whole new process may have been more challenging, but Frank described the plant staff as "mature, but not averse to

new technology, because this plant is the test bed for many products.” Second, the catalyst for the project was a neighborhood regulation, which was supported by employees living near the plant. The plant staff fully grasped the impact that the project would have on their own well-being, and therefore took ownership of the project. In fact, the plant proposed the system to be validated by P&PE and installed at the plant. Also, because the plant’s Area Manager had a strong process engineering background, he was able to lead his team through technical hurdles without relying heavily on P&PE. Finally, the plant’s union representative fostered cooperation. His support was essential, for example to allow two operators to be devoted to the project throughout the installation.

Another of GM’s assembly plants converted to powder primer years ago, and can be looked to as an example of successful implementation. According to Dana Morgan, Director Truck and Facilities, Paint and Polymers Engineering, two key enablers made the plant unique. First, plant leadership had instilled a disciplined culture at the plant long before the installation. Individuals were held responsible for the accomplishments and failures of the team. Second, many of the members of the paint organization had been working together in paint for years. They had gained great expertise with paint and took personal pride in being “paint professionals.” Most significant, they had built up long-lasting relationships internally and with suppliers. In fact, the relationships within the paint shop extended beyond working relationships, to friendships. The friends’ mutual pride and trust fostered teamwork, and thus led to a great achievement for the paint shop.

4.2.4. Methods and Recommendations for Change Management

Implementation of the canister system faces challenges; but strategic strengths have been identified. Plans based on the organizational processes analysis, plus tactics borrowed from previous projects, will aid in managing the installation and adoption of the new technology.

4.2.4.1. Introducing Change

The book, Four Practical Revolutions in Management: Systems for Creating Unique Organizational Capability, details management methods developed by Professor Shoji Shiba and the Center for Quality Management.⁸² Numerous leading companies and non-profit institutions

⁸² Shiba, Shoji, and Walden, David. Four Practical Revolutions in Management: Systems for Creating Unique Organizational Capability. Productivity Press and Center for Quality of Management, Portland, Oregon, 2001.

have succeeded through Shiba's methods, especially with respect to creating an effective change mobilization strategy. While Shiba focuses on implementing organizational improvement throughout a company, the guidelines are applicable to implementation of new technology as well. GM should consider Shiba's approach when initiating the organizational change that must accompany the technical advancements of the canister system.

Shiba stresses the importance of creating an explicit structure for mobilization: "The leader needs to build a support infrastructure that broadcasts the leader's vision throughout the organization and mobilizes action in support of the leader's vision."⁸³ Shiba's suggested model consists of seven elements. P&PE and Plant management have incorporated some of the elements, while others could be further developed.

For the first element, *goal setting*, Shiba recommends having an abstract "noble goal" that will motivate, "intermediate goals" that will guide strategy, and specific "annual goals."⁸⁴ With respect to P&PE, the noble goal of environmentally friendly manufacturing is clear. Implementation of the canister system is one of the intermediate steps toward that goal, and management has determined the yearly schedule for the project. The plant shares P&PE's noble goal and intermediate goal, while its annual goals focus more on operational objectives.

Shiba suggests that the second element, the *organization setting*, include a corporate change committee, "responsible for leading, diffusing, and managing change."⁸⁵ The project team has taken on this role, especially the plant representatives who will lead the continuing organizational adaptation after installation. The organization setting should also include a corporate change officer, to assist the top manager and change committee. The Assistant Plant Manager appears to fill this role.

The third element, *training and education*, will be discussed in detail in Section 4.2.4.2.

The fourth element, *promotional activities*, will generate enthusiasm at the plant about the upcoming change. Three dimensions of promotion, as shown in Figure 14, can be used.

⁸³ *Ibid.*, P423

⁸⁴ *Ibid.*, P427&428

⁸⁵ *Ibid.*, P431

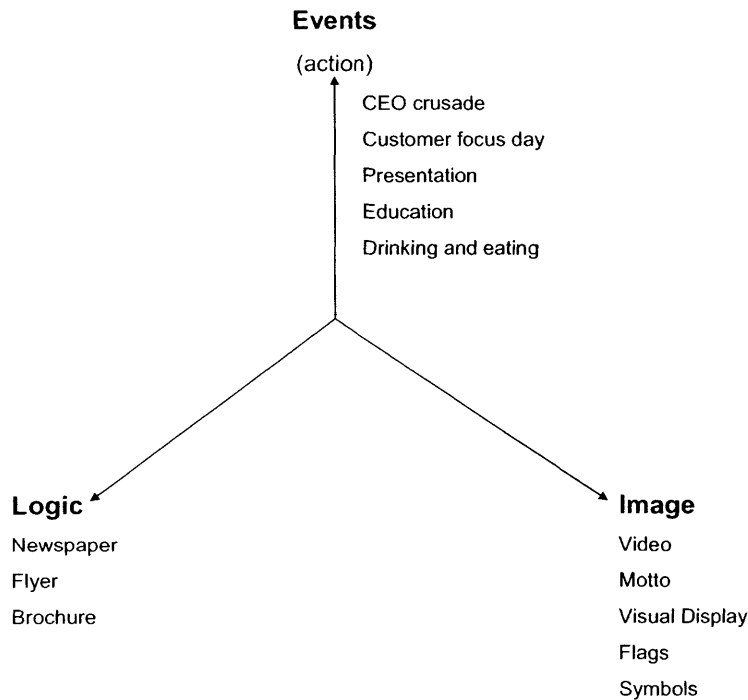


Figure 14: Three Dimensions of Promotion for Organizational Change and Improvement⁸⁶

A major event is planned for the new paint shop. Prior to final cleaning, the paint shop will be open to plant employees and families for tours. The Open House should help build the plant community, but the primary goal is to generate pride in the new facility and equipment. Parents, children, and spouses who have seen where their loved ones go to work will want to hear about daily accomplishments with the new facility. Also, employees who are exposed to the entire paint shop will better understand how their job contributes to the whole paint process.

Laying the groundwork for change must begin as early as possible. Logical activities could be used to explain the benefits of powder paint primer, and the canister system in particular. Videos could also be used, because as Shiba admits, “people don’t often read written material, which makes images more important.”⁸⁷ Presentations are being given to hourly employees as well as management at the plant, to publicize the “why” behind the project. A few promotional activities have been conducted, including printing articles in the plant’s weekly newsletter and displaying the new paint suits that must be worn in the paint shop. Bright images posted in the

⁸⁶ *Ibid.*, P441

⁸⁷ *Ibid.*, P441

old plant would easily catch people's attention. A motto such as "Dirt *can* hurt!" would help introduce the cleanliness standards for the new system. Visual displays for progress during installation and then start-up, such as a cartoon car moving through a paint booth and emerging fully painted when the goal is achieved, would also keep employees involved.

The fifth element of Shiba's model, *diffusion of success stories*, can be accomplished using a formal presentation system, as well as through informal communication between departments and plants. Success stories are often publicized when presenting awards. The sixth element includes both *awards and incentives*: "Awards can be thought of as recognizing desired behavior, and incentives can be thought of as encouraging desired behavior."⁸⁸ The last element, *monitoring and diagnosis*, is an ongoing self-assessment process.

Unlike many organizational improvement implementations, mobilization of the change to colored powder paint primer will have a physical component. The project team hopes that because the new paint shop is a completely separate entity from the existing plant and paint shop, employees will enter the new facility with renewed ambition. Culture has thus been designed in; especially with respect to cleanliness. The only entrance to the paint shop will be through a locker room for changing into coveralls and an air shower for removing loose hair and dirt, emphasizing the criticality of keeping the paint shop clean.

PSA Peugeot Citroen took a similar approach with the Mulhouse plant. Laurent Jeanningros explains:

Apart from the requirements associated with the paint process, an extremely high level of cleanliness must be maintained in the areas where staff are present, in order to promote good practices by the workers. The powder area is therefore separate from the rest of the workshop (there is an entrance chamber, curtain wall etc). A disposable overall and overshoes must be worn when entering the areas located closest to the application and distribution zones. We have observed that these measures act as a deterrent and minimise the number of persons entering these areas for no good reason.

The mere fact that the GM plant is receiving a well-designed brand-new facility should provide motivation for employees. By promoting clear goals for the new paint shop and celebrating success stories, leadership will help mobilize a longer-lasting pride and energy.

⁸⁸ *Ibid.*, P444

4.2.4.2. Managing Installation and Adoption of New Technology

Professor Shiba's research found that three phases are typical of successful organizational change: Orientation, Empowerment, and Alignment.⁸⁹ The phases often overlap, and can involve the seven mobilization elements, as well as other strategies for transferring knowledge and responsibility. The P&PE project team will manage the orientation, empowerment, and alignment phases for installation of the canister system.

The goal of orientation is to inform the plant of the goals for the project and the capabilities of the canister system. Because of their familiarity with the new technology, TD&V engineers play a large role in plant orientation. Ideally, TD&V engineers have the communication skills required to present the system to plant employees of all skill and management levels. Alternatively, GM's Failure Mode and Effects Analysis (FMEA) provides a forum for TD&V and plant representatives to discuss the operational and maintenance requirements of the new system. Participants can include the paint shop superintendent, maintenance personnel, shift foremen, selected operations personnel, onsite engineers, installation personnel, and supplier application engineers. These stakeholders are allowed to voice their concerns during an organized process review session. For each process step, the stakeholders brainstorm possible problems that may arise during operation of the new system. The TD&V engineer then builds consensus through the process of assigning risk and seriousness factors to each problem. After thus prioritizing problems, the group pro-actively develops solutions to the problems. From a technical standpoint, the analysis ensures that an implementation plan has been thoroughly considered from many different points of view, and that all stakeholders have explored the system design in some detail.⁹⁰ At least as valuable, the analysis provides an open communication atmosphere. The result is consensus support, with all of the stakeholders "on the same page." By participating in the planning process for the system through the FMEA, the plant is taking some responsibility for final system performance. This responsibility will encourage the plant to take ownership of the system after installation.

The empowerment phase will enable the plant to take ownership of the system. The third element of mobilization, *training and education*, is an imperative part of empowerment. Good education programs consist of formal training, both classroom and hands-on, as well as informal

⁸⁹ *Ibid.*, P453

⁹⁰ DeWitt, P118

exposure to the new system and processes. The goal is to teach not only information, but also skills, providing students with the knowledge necessary to work with the new technology.

Similar to the GM implementation, the PSA Peugeot Citroen Mulhouse Plant project involved the introduction of totally robotised application of primers and lacquers and the launch of coloured powder primers. PSA's training program was rigorous. In addition to courses developed specifically for the innovative aspects of the plant, a separate two-day training course was given to all staff, including approximately 80 maintenance specialists and 30 facility operators (Managers also underwent a reduced training schedule). Followed by a site visit, staff training covered all aspects of the plant. It included around sixty training modules with different suppliers, some of which took place on-site and some of which were conducted on the suppliers' premises. The theoretical training culminated in a practical test (in an emergency setting) in order to check the trainees' knowledge. The first trainees, including 32 maintenance specialists, were integrated into the project at the end of the installation phase.

Manufacturing Leader Glen Santelices is responsible for organizing the education program for GM's new paint shop. He outlined some of the key characteristics of the currently planned program. As with PSA's training program, the paint supplier will be providing basic courses about powder coatings. Unlike PSA, training specific to the plant's application will be scheduled over two weeks, rather than as a one or two-day crash course. This will allow technicians to work on a rotating schedule with the system integrator, gaining hands-on experience with the equipment. At the same time, a select group of personnel will be sent each month to a plant applying single-color powder primer, in order to gain more knowledge of the powder primer process. In particular, the visits to a plant more experienced with powder paint systems will provide an opportunity to see what kinds of problems may arise with longer operation, and how trouble-shooting might be conducted. By shadowing a process engineer, technician, or operator at the model plant, trainees would observe the kinds of problem solving skills and discipline needed to keep the paint shop operational. Rather than a single model plant, the plant visits might include a group of GM plants operating single-color powder primer systems. These visits would serve as part of the fifth element of mobilization, *diffusion of success stories*, allowing "best practices" to be shared between plants. During the plant visits, trainees would also be able to form valuable relationships for the future, as will be discussed in the next section.

GM's education program for the new paint shop seems complete, but one point to note is that only key personnel will be involved with the plant visits. With these employees being divided among three shifts, Santelices stressed that "You have to pick the right people. Then you enable them to teach the rest." In addition to picking the appropriate employees for training, it is

important to give them the opportunity to share their knowledge with the other employees. One situation that should be avoided is dedicating a team to each shift. A better education for all plant staff personnel will be achieved if teams are reorganized periodically, so that no team can rely on a single individual's expertise. Identifying natural leaders to attend training, and fostering knowledge sharing through cross-training, will be effective. This team-learning strategy incorporates some of the recommendations made by Professor Shiba regarding training: don't use education professionals to teach; use mutual learning, not the traditional teacher-student roles; and create opportunity for learning in daily routine work.⁹¹

P&PE's input into the technical and process-related content of the education program is critical. For new systems such as the canister system, TD&V engineers may actually be the right people to lead initial training. A limited period of dedicated post-installation support would also be beneficial. Whereas installation time must be devoted to starting up the system, P&PE could use the additional support time to transfer knowledge of the system and tips for trouble-shooting. P&PE must avoid becoming a crutch for the plant, however. One requirement during the stand-by period should be for a plant representative to accompany P&PE representatives during all trouble-shooting work. If possible, the P&PE representatives involved with stand-by support should be natural leaders who understand how to involve and empower a team of plant personnel, to eventually take on responsibility for the new system.

Finally, the alignment phase will ensure that everyone is working toward a common goal. The balanced scorecard is one way to combine multiple objectives and performance measures. While addressing the needs of all stakeholders, the balanced scorecard attempts to achieve balance between short- and long-term objectives, and between financial and nonfinancial performance measures.⁹² Usually applied at the company level, the balanced scorecard links the firm's strategy to performance drivers that provide a comprehensive view of the organization. The balanced scorecard approach can also be applied to specific projects, and could be used for evaluating all involved with the new canister system. The following key performance areas might be evaluated for the members of the project team:

- Meeting project budget
- Completing installation on schedule
- Customer service during installation
- Customer service during post-installation support

⁹¹ Shiba, P435

⁹² *Ibid.*, P702

- Quality of production at commissioning
- Quality of production over first year
- Reliability of system over first year

The plant team operating the new system after installation might instead be measured in the following areas:

- Training attendance
- Participation in Installation Support
- Production Output
- Operational costs
- Quality of production
- Reliability of system

Overlapping some of the performance measures for P&PE and the plant reflects GM's overarching focus on production and quality, while recognizing more specific objectives.

Although the balanced scorecard approach gives incentive for individuals to contribute, it does not keep track of the decisions that must be made and the actions that must be completed to support a change such as implementation of the canister system. A common technique for this kind of planning is responsibility charting, as described in a chapter entitled "Commitment Planning and Strategies," of Beckhard and Rubin's book Organizational Transitions – Managing Complex Change.⁹³ By clarifying the behavior required from each party involved in a change, responsibility charting helps reduce ambiguity, wasted energy, and adverse emotional reactions between individuals or groups whose interrelationship is affected by the change. The responsibility chart format is shown in Figure 15. The actions, decisions, and activities that affect the interrelationship are listed on the vertical axis. The horizontal axis lists the actors involved in each action or decision. The required behavior of each actor with regard to any particular action or decision can then be charted, using the following classifications:

R: Has *responsibility* for a particular action, but not necessarily authority

A: Must *approve* (has power to veto the action)

S: Must *support* (has to provide resources for the action, but not necessarily agree with it)

I: Must be *informed* or consulted before action, but cannot veto

-: Irrelevant to the particular action

The two ground rules for responsibility charting are that no more than one R can exist for each activity, and no box may contain more than one letter. While filling in the chart, then, the first

⁹³ Beckhard and Rubin. Organizational Transitions – Managing Complex Change. Addison-Wesley Longman, Inc., Massachusetts, 1987, P104-106

decision to be made is who has responsibility for each activity. Next, the parties contributing through approval or support, or who must be informed, can be identified.

The project team does currently use responsibility charting. The benefit of the charting process itself is that all involved gain understanding and appreciation of each other’s roles, and commit to their own roles. In the case of the canister system, another benefit is to integrate the multiple engineering groups. An example is illustrated by the following figure, which includes only a sample of the actors involved with the canister system. Although the TD&V engineer is responsible for validating the color changer to be used with the canister system, involvement of a materials engineer is required to ensure material compatibility. Facilities engineers may need to be notified of the power and air consumption of the color changer, in case facility adjustments are required. In addition, the plant may be consulted to help define the plant-specific testing requirements for the applicator. Understanding that assigning too many A’s would delay decision-making, Manufacturing Leader Glen Santelices asserted that throughout canister system implementation, “The plant at least needs to be informed about everything.” This is because so many engineering decisions will impact operational and maintenance procedures that will be conducted by the plant.

		ACTORS			
		Process Development	Materials	Facilities	Plant Maintenance
DECISIONS OR ACTS	Color changer validation	R	S	I	I

Figure 15: Sample Responsibility Chart for Canister System Validation

One last note to be made about managing installation is that the analysis in this chapter has focused on the organization formed by P&PE and the Plant. In truth, external forces act upon this organization as well. For example, the union representative can be a facilitator in empowering and aligning the union members for operation of the canister system. At any company, managers must consider factors that are indirectly involved with a change initiative.

Chapter 5: Summary and Conclusions

5.1. Summary

The automotive industry is adopting a new coatings system that replaces traditionally solvent-based coatings with powder primer, waterborne top coat, and powder clear coat. In order for the new system to perform as well as current liquid coatings systems, both color keyed and color specific powder primers must be applied. Application of multicolor powder with full reclaim and therefore 100% material utilization is technically feasible, but the delivery and application process for multicolor powder has not yet been optimized.

GM has developed an economical and compact process for applying multicolor powder primer, making use of the GM Canister Powder Paint Delivery System. While meeting cycle requirements, the canister system substantially reduces the required number of pieces of equipment necessary for delivery.

The MSQ Process is meant to address the technical requirements for the new system, ensuring not only that the individual components function, but also that the integrated system meets functionality and durability requirements under true production conditions. In the case of the Canister System, the MSQ Process has provided a framework for development as well as validation, with P&PE engineers working with the supplier to determine the system's capabilities and make improvements as appropriate. Formal and relational contracts have provided incentives that have allowed for successful collaboration.

The pilot plant will also be involved throughout the MSQ Process, which serves as a bridge between development and operation. Plant participation in testing provides an opportunity to transfer knowledge from the P&PE engineers to the plant staff. Formal training, as well as learning best practices from plants applying single color powder primer, will additionally empower the staff to take ownership of the new system. At least as important as technical preparation, the culture of the plant organization will need to adjust to the more complicated operational requirements of the new manufacturing technology.

5.2. Next Steps

The next step would be to implement multicolor powder primer application at GM North America plants. Because the operating conditions will be somewhat different between plants, technical requirements must be reviewed, and MSQ Phases 1 and 2 conducted, for each plant.

Organizational requirements must be reviewed as well, because the structure and culture at each of these plants will be unique. Capturing lessons learned at the pilot plant and applying them to all future implementations will be invaluable.

At the same time, implementation could be expanded to GM's production facilities worldwide. P&PE engineers have been working with coatings engineers at each of GM's international divisions, to develop global standards for currently used processes including single color powder primer. Standards for multicolor powder primer application processes would be developed internationally as well. Finally, P&PE engineers should consider applications for the canister system beyond multicolor powder primer. If materials engineers and process development engineers can address the challenges to powder top coat, in particular the problems with powder coating metallics, the canister system could be part of an improved alternative coatings system: powder primer, base coat, and clear coat.

5.3. Conclusion

In designing the MSQ Process, GM has recognized that the validation process can serve both a technical and organizational purpose. Technically, MSQ addresses the requirements of the system, versus individual components, and accounts for the inadequacies of lab testing. Organizationally, MSQ requires the cooperation of all parties involved with development, validation, and operation. This ensures that suppliers understand the operator's needs, and that knowledge of the system is transferred from the suppliers to the operator. If the system has been designed with the operator's input, and the operator has gained enough familiarity with the system; the operator should be willing and able to take ownership of the new system, and successful technology transfer should occur. Including plant representatives on the project team and involving them in the MSQ Process encourages the plant to begin taking ownership during the installation process, rather than after production has begun. P&PE has thus led the MSQ Process for the GM Canister Powder Paint Delivery System, involving the supplier and the plant throughout, so that GM's implementation of multicolor powder primer application will be an outstanding accomplishment.

Bibliography

- Beckhard and Rubin. Organizational Transitions – Managing Complex Change. Addison-Wesley Longman, Inc., Massachusetts, 1987.
- Beuerle, James Edward, Jr. “A Study of Electrostatically applied Powder Paint in the Automotive Industry.” *Massachusetts Institute of Technology*, June 1996.
- Bonifant, Ben. “Competitive Implications of Environmental Regulation in the Paint and Coatings Industry.” *Management Institute for Environment and Business (MEB)*, Washington, D.C.: 1994.
- Carroll, John S. “Introduction to Organizational Analysis: The Three Lenses.” *Sloan Management Review (MIT Sloan School of Management)*, 2001.
- DeWitt, Charles M. “A Holistic Approach to Automotive Powder Coating.” *Massachusetts Institute of Technology*, June 1995.
- Diem, William. “PSA’s New Mulhouse Paint Shop to Use Powder Primer.” *WardsAuto.com*, March 20, 2003.
- German, Shaun. “Ultrasonic Deblinding System Improves Powder Coating Sieving.” *Paint & Coatings Industry*, Troy: July 2003, Vol. 19, Iss. 7.
- Johnson, Jeffrey C., Joyce, Jeffrey R., Kolarik, William. “Multidimensional Design, Multicolor Powder Primer.” *Metal Finishing [H.W. Wilson – AST]*, May, 2000, Vol. 98, Iss. 5.
- Kilbanoff and Novak. “Contracting, Directed Parts, and Complexity in Automotive Outsourcing Decisions.” *Kellogg Graduate School of Engineering, Northwestern University*, Evanston, IL: 2003 (Version 2.1).
- Koch, PE, William. “Power Transformer: From Specs to Installation.” *Electrial World*, New York: January/February, 2000, Vol. 214, Iss. 1.
- Leach, Lawrence P. Critical Chain Project Management. Artech House, Inc., Norwood, MA, 2000.
- Lis, Karen and Messerly, Eric R. “Powder Primer Surfacer Technology Implementation.” *International Body Engineering Conference*, May 23, 1994.
- Meschievitz, T.A., Pearson, R.F., and McLaughlin, E.O.. “USCAR: Automotive Powder Clearcoat Experience.” *Metal Finishing [H.W. Wilson – AST]*, August, 1997, Vol. 95.
- Murphy et al. “Multicolor Powder Coating Application of Automotive Primer Surfacer.” *Powder Coating*, March 2002.
- Nallicheri, Renu Agawal. “Automotive Painting – An Economic and Strategic Analysis.” *Massachusetts Institute of Technology*, December 1993.

- S.Papasavva et al. "Characterization of Automotive Paints: an Environmental Impact Analysis." *Progress in Organic Coatings*, 2001, Vol. 43.
- Robinson, Peter. "Ferrari HQ to Undergo Massive Renovation." *WardsAuto.com*, August 12, 2002.
- Schreffler, Roger. "Paint is Poised for Cleaner Role, Improved Product." *WardsAuto.com*, February 15, 2001.
- Shiba, Shoji, and Walden, David. Four Practical Revolutions in Management: Systems for Creating Unique Organizational Capability. *Productivity Press and Center for Quality of Management*, Portland, Oregon, 2001.
- Wimmer, Walter. "Powder Clearcoat, a Leap in Paint Technology." *Automotive Engineering International [H.W.Wilson – AST]*, February, 2001, Vol. 109, Iss. 2.
- Woodcock, MD, Janet. "FDA Regulation of Drug Quality: New Challenges." Presentation Slides, April 9, 2002.
- Zimmerman, Jerold L. Accounting for Decision Making and Control, Fourth Edition. *McGraw-Hill Irwin*, New York, NY, 2003.
- "DC to Test Advanced Paint Systems in Canada." *WardsAuto.com*, September 25, 2000.
- "System Integrator Helps GM Minimize its Time to Market." *Tooling & Production*, Solon: May 2000, Vol. 66, Iss. 2.
- Code of Federal Regulations, Title 21 - Food and Drugs, Part 820 - Quality System Regulation. April 1, 2003.
- Quality System Manual. *U.S. Food and Drug Administration, Department of Health and Human Services, Center for Devices and Radiological Health*, 1997.
- "Surface Coatings Process Control Relationship Manual, General Information." *GM Paint & Sealing*, Document 34700.
- "Surface Coatings Process Control Relationship Manual, Primers Process Control Relationships." *GM Paint & Sealing*, Document 34700.