Pollution Prevention at Los Alamos National Laboratory
Reducing Pollution from Road Stripping Operations

Dianne Williams Wilburn, Environmental Stewardship Office,
Los Alamos National Laboratory, Los Alamos, New Mexico
Suzanne Hartnett and Stacy Richardson, Benchmark Environmental Corporation,
Los Alamos, New Mexico.

1.0 Background

Johnson Controls Northern New Mexico (JCNNM) is the facility support subcontractor to the Los Alamos National Laboratory (the Laboratory), in Los Alamos New Mexico. JCNNM operates and maintains the Laboratory facilities, equipment, property, grounds, infrastructure, and public and private roadways covering over 27,800 acres. All work is conducted on behalf of the Laboratory and the Department of Energy.

JCNNM services include the maintenance of an estimated 50 linear miles of paved roadways and over 1 million square yards of parking areas. JCNNM recognized that the process used to apply pavement markings on roadways and parking areas (e.g. road-stripping) was a routine and significant source of waste generation and pollutant emissions, including solvent-based paint wastes, air emission, and potential storm water pollution sources from the applied paint. As part of their commitment to Pollution Prevention, the JCNNM Roads Department (MDSR) initiated an effort to identify alternatives that would prevent or reduce these emissions. Working with the Laboratory's Environmental Stewardship Office (ESO), JCNNM MDSR began a systematic process to evaluate and implement P2 opportunities for the road stripping operation.

This paper presents the systematic approach used by JCNNM and ESO to reduce pollution from the road-stripping operation (and life cycle), utilizing the *New Mexico Green Zia Systems Analysis Tools* (Green Zia tools). Use of the Green Zia Tools is specified in Functional Area 3 (Managerial Accomplishments) of Section B, Part II-1, Appendix F of the DOE/University of California contract (1999). In general, the Green Zia analyses were accomplished according to New Mexico Green Zia Environmental Excellence Award program (reference). In some cases the application of the tools was customized to meet the specific challenges of the road-stripping operation.

The paper discusses the application of the following tools:

- Process mapping of the current operation
- Rank ordering of the opportunities
- Root cause analysis. .
- Consensus problem statement.
- Generating process alternatives
- Selecting an alternative
- Implementing the selected alternative with a formal action plan

JCNNM has 13 major departments at the Laboratory, and over one hundred processes that may generate waste or emissions. There are an estimated 40 distinct waste streams generated by JCNNM operations (based on FY 98 data), including RCRA hazardous waste, TSCA regulated wastes, NM special and industrial wastes, and solid/sanitary wastes. In addition to waste streams, JCNNM operations also produce air and water emissions that are regulated under the state and federal clean water and air regulations.

JCNNM has an ongoing and formal pollution prevention program committed to reduce waste and emissions. The P2 Program is documented in a written plan (*The Waste Minimization Pollution Prevention Program Plan for Calendar Years 1997 through 1999* , SPI 12-31-012) and P2 practices are incorporated into operating procedures, where appropriate. In addition, JCNNM has P2 performance measures included in their contract with the Laboratory which influence their subcontract award fee. These documents specify JCNNM commitment to preventing waste at the source, and recycling and minimizing waste that can not be prevented. They outline P2 requirements, establish numeric goals for reduction of wastes, require tracking and reporting of progress toward meeting the goals, and provide incentives or rewards for waste reduction. Under JCNNM's P2 program, Department Managers (and others that supervise waste generating operations) are challenged and required to incorporate P2 practices to the extent technically and economically feasible.

2.0 The Challenge

The Laboratory area encompasses over 27,000 acres, including an estimated 50 linear miles of paved roads and walkways and over one million square yards of parking areas. JCNNM MDSR maintains the roads and traffic areas, and these require frequent application of transportation and pavement markings (e.g. road stripping) to ensure safe and effective travel of both autos and pedestrians. Currently, MDSR meets road stripping requirements using oil based paints that are sprayed onto paved surfaces.

Routine road stripping operations include:

- Marking side lines and center lines along all roads
- Traffic markings in high traffic areas and intersections
- Cross walk markings
- Parking lot markings

The road stripping operation generates solvent-based waste that must be managed and disposed as hazardous waste (under the provisions of the Resource Conservation and Recovery Act, RCRA). In addition, the operation is a routine source of airborne emissions (volatile organic compounds and paint overspray), and the applied paint is a potential storm water pollution source and a potential source of lead chromate and other heavy metal compounds that are often found in oil-based paints.

Recognizing that their current process was a significant source of waste and pollutants, MDSR's challenge was to identify an alternative process that would reduce pollutant emissions without reducing the operational performance of the road-stripe product or increasing the cost of the operation. This means that any alternative process must maintain (or enhance) the function, operation, and durability of the road stripping, reduce the waste and emissions generated through the life cycle of the road-stripe, continue to meet state and federal traffic standards, and be cost effective.

3.0 The Team

The effort to identify an alternative road-stripe process was initiated by the manager of JCNNM Roads Department. The ESO assisted JCNNM with the systematic evaluation and application of the Green Zia tool. The team members for this effort included:

- Alicia Hale, Team Facilitator, Environmental Stewardship Office, Los Alamos National Laboratory,
- Dianne Williams Wilburn, Environmental Stewardship Office, Los Alamos National Laboratory,
- Robert Walker, JCNNM, Manager, MDSR
- Suzanne Hartnett, Environmental Engineer, Benchmark Environmental Corporation
- Stacy Richardson, Environmental Engineer, Benchmark Environmental Corporation

The team also would like to acknowledge the assistance provided by Ronald Riggins, and others from the JCNNM Painting Operations.

4.0 Process Characterization

A description of the current road stripping operation is provided below. After reviewing this information, the team prepared a process map and they identified performance requirements for the road-stripping product.

The current operation uses a "Road Striper" vehicle that sprays an oil-based paint onto road surfaces. The vehicle, similar to many used throughout the country, is driven slowly down a road while spray-painting centerlines and sidelines. Labor is required to operate the vehicle, supervise the paint application, and for traffic control. The system uses air-assisted spray paint guns, pressurized by an air compressor. This type of spray system has a paint transfer efficiency of only 15 to 30%, meaning that a high amount of paint does not reach the object being painted but is lost to the environment as overspray.

Crosswalks, parking lots, and other specialized traffic markings are applied using an airless sprayer machine that requires an operator (who walks behind the equipment) and traffic control. Templates may also be required for specialized traffic markings (such as STOP , PED XING, etc) to ensure compliance with traffic standards. The airless sprayer machine may have a higher paint transfer efficiency of up to 40%. While the transfer efficiency of the JCNNM equipment is not precisely known, an average of 40% was assumed for this study.

Typically, the painted traffic markings are re-applied at six-month intervals.

4.1 Process Map

Figure 4.1 shows the process map for the operation [1]. Material and resource inputs are shown as arrows at the top of each work step; and material losses, waste or emissions are shown as output arrows at the bottom of each step.

The material losses and environmental emissions shown in the map include:

- Vehicle emissions (from gasoline powered vehicles)

[1] Process maps illustrate the work steps that materials and resources pass through as they are transformed into final product. The map identifies inputs and outputs from a process and it is helpful to identify wastes, emissions or losses.

- Dust
- Volatile organic compound emissions (from paint and thinner)
- Paint overspray
- Solvent-based thinner and paint waste including excess, unusable paint (RCRA regulated)
- Paint and solvent soaked rags (RCRA regulated)
- Empty containers from leftover/spent paint (may be RCRA regulated)
- Potential storm water pollution sources from paint chips, lead chromate or other heavy metal compounds often found in oil-based paints.

Quantitative data is available only on the paint, thinner, and rag waste streams (which are managed as RCRA waste). These waste streams account for an estimated 1500 kg of RCRA hazardous waste per year; and for up to 25 % of total waste RCRA generated by JCNNM operations.

4.2 Performance Requirements

The team identified the following performance requirements for the road stripping process. These performance requirements were considered during the identification and selection of P2 opportunities and alternatives, as discussed in section 9.0

- Installation Requirements, such as equipment, training, or limitations due to weather/temperature;
- Visibility, skid resistance, reflection ability, and durability of the product;
- Meeting state and federal traffic standards; and
- Worker health and safety issues.

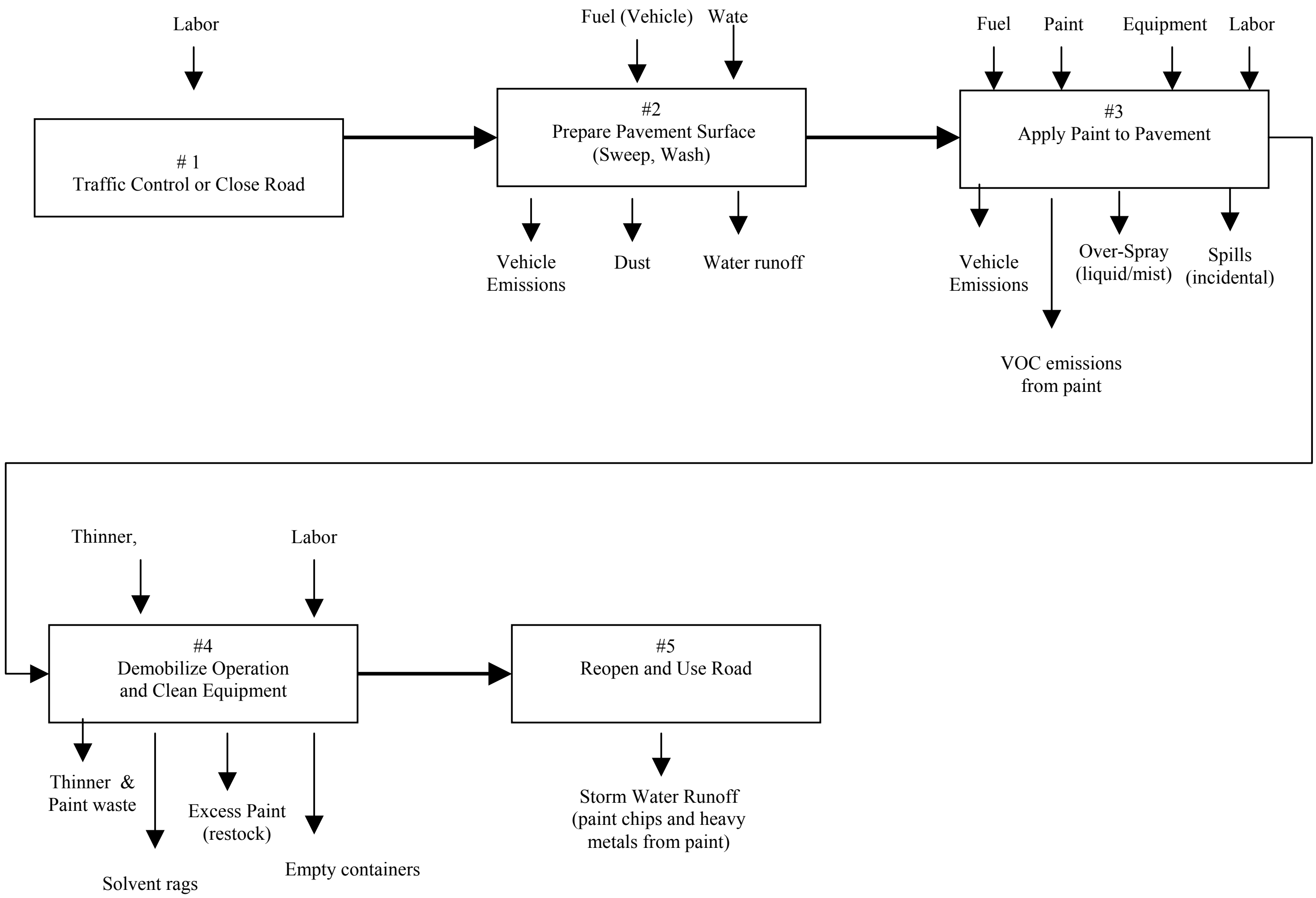
5.0 Rank Ordering of Opportunities

To identify and rank P2 opportunities, the team evaluated cost and operational data for the road stripping process and used the information to estimate Activity-Based Costs. This information provided a better understanding of the road stripping process and it allowed the team to identify and target high-cost activities or high-loss activities.

General operational information is shown in Table 5.1. The information was collected (and calculated) from operating experience, facility records, and supplemented by vendor information and reference material, where appropriate. From this information, activity-based costs were extrapolated, and are shown in Table 5.2. Overhead and indirect costs were not accounted for separately, due to the JCNNM and Laboratory accounting systems, but they are assumed to be included in the fully burdened labor and materials costs.

The Activity Based Cost analysis indicated that Activity #2, "Apply Paint" is the most expensive due to the cost of the paint material, the paint material that is lost or wasted (to overspray) and the labor. The second most expensive activity is "Demobilize and Clean Equipment". Therefore, the top ranked P2 opportunities should focus on reducing the material and losses associated with applying paint and demobilizing and cleaning the equipment.

Figure 4.1 Process Map of Current Road Stripping Operation



6.0 Root Cause Analysis

The team conducted a cause and effect analysis of the road stripping process. They prepared a fishbone diagram, shown in Figure 6.1, to illustrate why " the road stripping process generates RCRA waste and losses material to the environment. The analysis looked at the methods, machines, people, and materials that could contribute to the problem.

7.0 Statement of Problem

This step was not conducted for this study. The root cause analysis was determined to fully describe the problem.

8.0 Generating Alternatives

JCNNM and the team identified the following as possible alternatives to the paint-based road stripping operation:

A. Substitute water-based paint for the oil-based paint used in the existing Road Stripper equipment
B. Recycle the solvent based wastes that are generated
C. Replace or modify the Road Stripper and sprayer equipment to use water-based paints
D. Do not do road stripping (or do it less frequently)
E. Use Thermoplastic pavement markings in place of painting
F. Use 3-M (or similar) plastic tape marking in place of painting

Alternatives A through D are self-explanatory. Brief descriptions of Alternatives E and F are provided below.

- Thermoplastic pavement markings are a non-paint, pre-fabricated plastic product that is positioned on the pavement and heated into the asphalt to become part of the asphalt. They can be used for center and side road stripes, as well as for traffic and intersection markings, cross walks, parking lots, and in high traffic areas. The product is pre-shaped and pre-cut to meet federal and state traffic standards when ordered. Thermoplastic striping can be applied in a variety of temperature and weather conditions and the applied product is skid resistant, and highly visible and reflective. No hazardous materials are used in the application of the product and no hazardous wastes are generated from the operation. The product has been road tested since the 1980s by motorists in the United States, Europe, Australia and Asia with positive results. The product also has a proven track record in Los Alamos, having been used for over four years by the LA County road crews in high traffic, cross walk and parking applications. Based on local experience, the plastic traffic markings must be re-applied after four years. Before re-application, the old markings must be removed using a grinder.

- Plastic tape pavement markings are a plastic tape product that is applied directly to the road to produce center and side road strips. It is a non-paint product and it is packaged in rolls of tape. It is applied with a special taping machine that is vehicle mounted/driven. No hazardous materials are used in the application of the product and no hazardous wastes are generated from the operation.

Table 5.1 Information on Road Stripping Operation

Miles of pavement markings painted per application cycle:	
Center and Side Strips:	49 linear miles
Cross walks, high traffic	5 miles[a]
Parking areas:	90 linear miles[b]
Applications required per year:	2
Total miles painted per year	288 linear miles
Budget per year for road stripping	~ $200K
Estimated Cost per mile	$690/mile (calculated value)
Materials Used	
Paint used per mile of road	120 to 150 gallons/mile (avg 135 g/mile)
Paint used per application cycle	~ 20,000 gallons
Thinner used per year:	50 gallons
Transfer efficiency of sprayer equipment	15 to 40% (40% assumed in calculations)
Labor requirements:	
Traffic control; applying paint (w/vehicle or w/sprayer); cleaning and demobilizing equipment; handling waste; training for traffic markings	
Waste and emissions	
Waste cost for RCRA waste:	$ 12.75/kg
RCRA Waste Streams	1200 kg/year ($15,300 per year)
Containers from leftover/spent paint	
Excess, unusable paint	
Equipment cleaning waste (Waste solvent, Paint sludge)	
Paint and solvent soaked rags	
Potential Spills of paint, solvent, vehicle fluids (gasoline, glycol, etc)	
Air emissions: including VOC air emissions and Paint overspray	
Dried paint chips or residual	
Fuel use and vehicle Emissions	
Overhead or Indirect Costs	
Safety & health support; Environmental support (compliance inspections, waste management coordinator support) ; Work Control Support; Support for off-normal situations (e.g., spill response); Safety & health training	

[a] Assumes 0.05 mile of painted areas per crosswalk or pavement area and 100 cross walks or high traffic areas

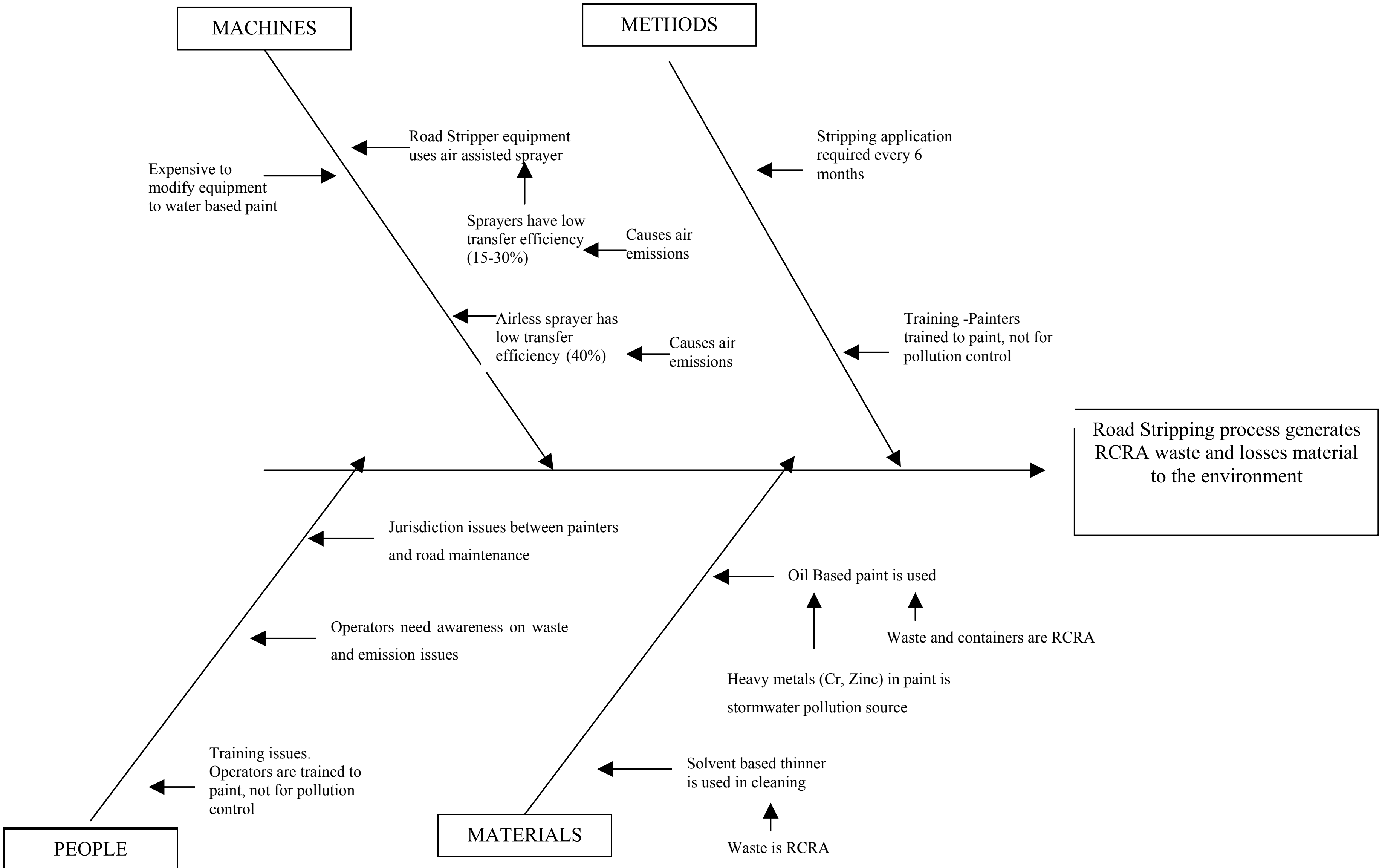
[b] Assumes parking area of 320 sq. ft per space (source: Civil Engineering Reference Manual, Traffic Analysis, Transportation and Highway Design); 13 ft of painted area per space; 269 acres of parking area LABORATORY wide (source: JCNNM Paint Department)

Table 5.2 –Activity-Based Cost Estimate

Activity	Cost Elements[a]		Cost
1 Traffic Control	Labor Overhead[b]:	 Specialized Training	$50/hr
2 Prepare Pavement	Labor Materials: Losses: Overhead :	 Vehicle fuel; water Emissions; Dust, Runoff Specialized Training, PPE/H&S	$50/hr not quantified (NQ) No quantifiable costs
3 Apply Paint	Labor Materials: Losses: Overhead :	 Paint; Thinner Paint overspray, VOC emissions Specialized Training	$50/hr $1400 /mile $850/mile (based on 60% of paint material lost)
4 Demobilize & Clean Equipment	Labor Materials: Losses: Overhead :	 Thinner RCRA Waste Environmental & Waste Support	$50/hr $ 3/ mile $ 52/mile
5 Reopen,Use Road	Losses:	Storm runoff	No quantifiable costs
Overhead Costs for all Activities: Work Control Support Environmental Support Support for Off normal conditions (e.g. spills, H&S Emergencies) Health and Safety support[c]			

[a] Only major cost elements are identified.
[b] Overhead costs applicable to all activities are shown in last row. Overhead costs (such as special training or Waste Coordinator support) are shown for the individual activities.

Figure 6.1 - Cause-Effect Diagram for Road Stripping Operation



9.0 Selecting Alternatives

The team discussed and compared the alternatives and applied the following criteria to identify a top ranked selection: *A selected option must maintain or enhance the performance of the road striping; continue to meet state and federal traffic standards; reduce the waste and emissions generated through the life cycle of the road-strip; and be cost effective.* In addition, the team wanted the selection options to reduce the cost of the labor, material, and losses from the application of the paint and from the demobilizing and cleaning the equipment, which was the top ranked opportunity identified by the team in Section 5. The team's selections are discussed below.

Selection #1. The top selected option was a combination of Alternatives E and F, using both Thermoplastic and Plastic Tape products with the tape used on center and side-stripes and the Thermoplastic used for high traffic and intersection markings, cross walks, and parking lots. The use of thermoplastic and plastic tape markings had been identified by JCNNM during the summer of 1999. JCNNM determined (and the Green Zia team agreed) that these were the most favorable alternatives based on information and communication with trade organizations, vendors, and the Los Alamos (LA) County municipality. The County road crews have demonstrated, hands-on experience using the Thermoplastic and tape pavement marking products locally on the county roads near and around the Laboratory. This proven track record in the local setting (e.g. high-altitude, intense sun, and heavy winter conditions) provided a strong basis for a high selection ranking by the team.

Selection #2 was Alternative C, modify the equipment to use water-based paints. This option was ranked lower because it did not address the top ranked opportunity (from Section 5) of reducing the cost of the labor, material, and losses from the application of the paint or from the demobilizing and cleaning the equipment. In addition there were concerns that water based paints would not provide the performance needed to stand up to existing road conditions; and, the cost of converting the existing sprayer equipment to accommodate the change in paint was unknown. It was decided that additional information was needed on this option.

Alternatives A, B, and D were not selected and were eliminated from further consideration for the following reasons:

- Alternative A, "Substitute water-based paints" was determined to be not technically feasible because of limitations of the existing equipment.
- Alternative B, "Recycling of the solvent wastes", was implemented during 1999. The option was not considered further in this study because it did not address the top ranked opportunity (Section 5) of reducing the cost of the labor, material, and losses from the application of the paint or from the demobilizing and cleaning the equipment.
- Alternative D, "Do not do road stripping (or do it less frequently)", was eliminated because it would not meet the operational and safety requirements of the JCNNM Roads department.

At this point, the team elected to do a direct (forced pair) comparison of the Thermoplastic option and the current paint-based operation. The comparison considered operational performance, P2 performance, and the life cycle cost of the two processes. Operational performance considered: installation requirements (specialized equipment, training, or limitations due to weather/temperature); the visibility, skid resistance, reflection ability, and durability of the product; the ability to meet state and federal traffic standards; and worker health and safety issues. P2 performance considered : Waste generated (or avoided); Pollutant emissions generated or avoided, and if the raw materials used in the process were consistent with Laboratory goals of using materials that are environmental preferable or contain the recycled content. Relevant information about the Thermoplastic is shown in Table 9.1; and a process map for the operation is shown in Figure 9.1.

The comparison of the two options is summarized in Table 9.2 and Table 9.3 shows an Activity Based Cost comparison of the options, for a typical life-cycle application to one cross walk.

The results of the forced pair comparison showed that the Thermoplastic system is the preferred process. It has a lower life cycle cost, because of its durability and because it generates no waste and no emissions. The thermoplastic, therefore, provides satisfactory performance with reduced material use, reduced emissions, and reduced overall costs.

10.0 Implementing Alternatives/Action Plan

The Thermoplastic process was identified as the preferred process, providing satisfactory performance with reduced material use, reduced emissions, and reduced overall costs. An action plan was identified for follow up and implementation of the alternative. However, there was still interest in the use of water based paints (Alternative C identified above). Therefore, further investigation into Alternative C was identified as part of the action plan prior to implementing any alternative. The Action Plan is as follows:

Action 1) Present results of study to LABORATORY Customer (Richard Fox) and JCNNM Managers; obtain recommendation and support to change the process (based on results of #2 below).
Responsibility: JCNNM MDSR
Deadline: Nov 2000

Action 2) Conduct additional research on technical and cost feasibility of Alternative C, modify the equipment to use water-based paints. Compare results of Thermoplastic applications. Select favorable Alternative. Notify ESO and JCNNM Environmental
Responsibility: JCNNM MDSR
Deadline: Jan 2000

Action 3) Work with vendor to schedule pilot test of new process
Responsibility: JCNNM MDSR
Deadline: April 2000

Action 4) Establish Metrics to be used during pilot test (cost, performance, and environmental) to monitor operation
Responsibility: JCNNM MDSR with Environmental support and ESO support
Deadline: April 2000

Action 5) Develop procedures for full-scale implementation of new operation; Train personnel on procedures
Responsibility: JCNNM MDSR with Environmental support
Deadline: June 2000

Action 6) Implement new operation; monitor progress
Responsibility: JCNNM MDSR
Deadline: June 2000

Table 9.1 Information for Thermoplastic Markings

Area Marked: **Reapplication**: **Cost per application:**	Same as with Painting Operation Once every 4 years 4 times that of painting (for labor and materials)
Labor requirements:	Traffic control + Operate the application equipment
Material Used	Skid resistant, highly visible, reflective Product is re-shaped and pre-cut to meet traffic standards, No need for special templates or training Can be applied in a variety of temperature conditions; asphalt must be dry before application No hazardous materials are used in the application of the product
Waste and emissions	Propane fuel use and vehicle emissions No RCRA waste generated Packaging containers can be recycled (as cardboard/paper) Excess product can be restocked (excess is limited because product is pre-cut) No air emissions
Overhead or Indirect Costs	Safety & health support No Environmental support required, since no regulated waste generated Work Control Support Support for off-normal situations (e.g., spill response)

Figure 9.1 Process Map for Thermoplastic Marking System

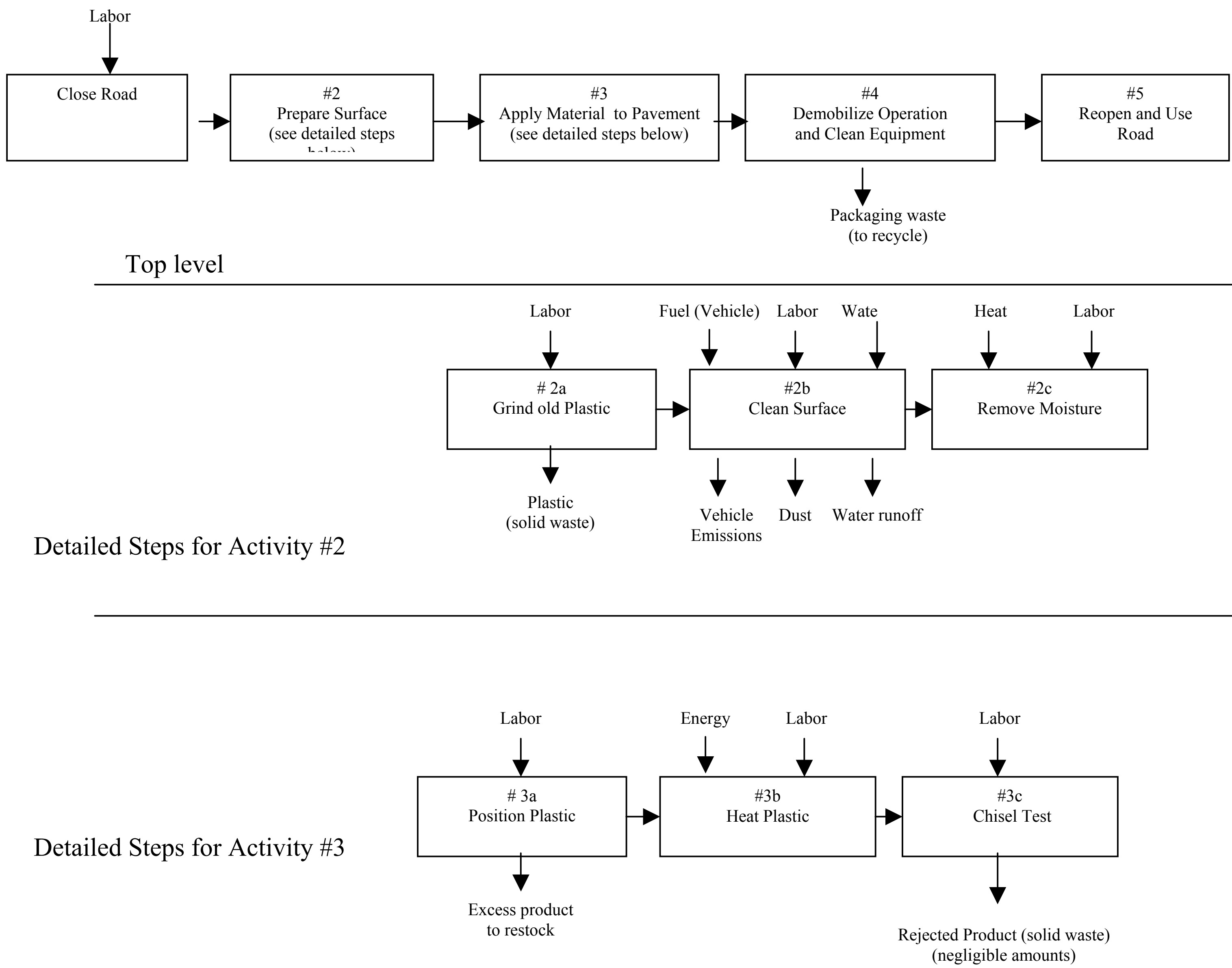


Table 9.2 Comparison of Paint Based Road Stripping and Thermoplastic Pavement Markings

Operational Performance Performance and Proven Track Record • Both operations provide satisfactory performance; both have proven track records in Los Alamos County. • Thermoplastic markings are more skid resistant, more visible and more reflective than paint, which improves safety of motorists and pedestrians. • Visibility of thermoplastic lasts throughout its service life (4 years); Visibility of painted product reduces with time. : Meets Traffic Standards • Both operations meet the traffic standards. • Thermoplastic is pre-cut to meet traffic standards; Painting may require templates or specially trained personnel to design and position traffic markings to meet standards. Durability • Plastic applications last eight times longer than the paint. (Reapplication is typically required every 4 years) ; Painting operation requires reapplication every 6 months Installation • Labor requirements are similar for application. Thermoplastic has no labor requirements for cleaning equipment or managing waste • Thermoplastic extends the road stripping season because there are no minimum road or air temperature requirements; Both operations must be used in dry conditions • Thermoplastic requires no specialized equipment or training • Failure of the thermoplastic product can occur from poor application/installation. Health and Safety • Thermoplastic application reduces time that workers are on the road and time that traffic is obstructed because it is pre-cut to size. • Thermoplastic reduces worker exposure to hazardous materials, waste, and paint overspray. • Specialized waste management/Environmental support is needed for management of RCRA wastes from painting operations. No special environmental support is required for Thermoplastic.
P2 Performance Waste generated • Paint operation generates RCRA waste; Thermoplastic generates no hazardous waste • Excess (old, expired, and unusable) paint may require disposal; excess thermoplastic product can be reused. • Paint Containers must be managed as RCRA waste; packaging of Thermoplastic is cardboard that is solid/sanitary waste or can be recycle. Pollutant emissions • Painting operation losses material to the environment from volatile air emissions and paint overspray; Thermoplastic has no air emissions • Painted road strips are potential storm water pollution source. Thermoplastic does not contain the heavy metals in paint that can leach to storm water. Environmental preferable or recycled materials used • Painting operation uses high quantities of hazardous materials each year, including oil-based paints and solvent based thinners. • Thermoplastic uses no hazardous materials.

Table 9.2 Continued

Life Cycle Costs
• Per application, thermoplastic is 4 times more expensive than painting. (based on labor and materials only, excluding waste management) • For life cycle, thermoplastic is 50% less expensive (8 applications of paint per 1 application of plastic) (based on labor and materials only, excluding waste management) • Total cost over life cycle, including waste management costs, Thermoplastic is 45% less expensive than painting.

Table 9.3 –Activity-Based Comparison
(Based on equivalent life cycles for a CrossWalk)

Activity	Cost Element: Paint Based Operation	Thermoplastic Operation
1 Traffic Control	Labor $50/hr Overhead: Training	$ 50/hr; Reduced time on road will reduce total cost Overhead: Training
2 Prepare Pavement	Labor $50/hr Materials: Vehicle fuel; water Losses: Emissions; Dust, Runoff Overhead : Specialized Training, PPE/H&S	No Significant Change in cost elements
3 Apply Paint	Labor & Materials: $ 1600 for life cycle (Paint & Thinner) Losses: $ 950 for life cycle (Paint overspray, VOC emissions) Overhead : Specialized Training	Labor & Materials: $800 for life cycle (plastic products) Losses: none Overhead : Specialized Training
4 Demobilize & Clean Equipment	Labor $50/hr Materials: $ 1.2 for life cycle (thinner) Losses: $ 1871 for life cycle (RCRA Waste) Overhead : Environmental & Waste Support	Labor none required for cleaning or waste management Materials: none Losses: none Overhead : none
5 Reopen,Use Road	Losses: Storm runoff	Losses: Storm runoff

11.0 References

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