NDOT Research Report

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Innovative CO2 LASER-Based Pavement Striping and Stripe Removal

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Nevada Department of Transportation

1263 South Stewart Street

Carson City, NV 89712

Disclaimer

NEVADA DEPRTMENT OF TRANSPORTATION

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FINAL REPORT

Innovative CO2 LASER-based Pavement Striping and Stripe Removal

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INNOVATIVE CO2 LASER-BASED PAVEMENT STRIPING AND STRIPE REMOVAL

CONTENTS

Summary

This is a Technical Report of an FY2014 NDOT funded project on Innovative *CO2 Laser-based Pavement Striping and Stripe Removal*. The project was concerned with adopting the laser technology for pavement stripe and markers removal and inferring on its economic, environmental and operational characteristics. The report contains a comparison of conventional methods with the new laser ablation technology based on the operation of the laboratory-scale prototype. It is also demonstrated that although the cost of a full-scale operational system would be higher than that of currently used systems, the advantages such as absence of ghost lines, fewer equipment breakdown delays, environmentally friendly operation and practically no pavement damage make the laser technology a promising alternative to the current practice.

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1. Current methods for paint stripe removal

While there are several methods which are currently used for stripe removal grinding, sand blasting and water jetting are predominantly used (see for example, [1,2]). Below we provode a brief description

1.1 Grinding

Grinding method of stripe removal is very widely used. There are various types of grinding machines depending upon the size and the scope of the project (Fig.1). A simple machine for a small project may involve a walk behind equipment which grinds the stripe off when pushed forward. Large machines have multiple grinding heads and are power driven. The grinding actions (See, Fig.2) in addition to the stripe removal also take off about 1/8 inch to a 1/4 inch of the pavement. This scarring action creates an indentation (damage) on the roadway surface - a ghost stripe. Dust is created during the grinding operations.

Small projects

Medium size projects

Large projects

Fig.1. Grinding equipment for different size projects

Fig.2: Grinding operations

1.2 Sand Blasting

Sand is used to blast the stripe surface (Fig.3). The accuracy of the removal depends upon the operator doing the sand blasting. The process creates a large volume of waste which must be disposed in accordance with the state and federal environmental laws.

Fig.3 Sand blasting operations

1.3. Water blasting

A high pressure jet is used for removing stripe. This method cannot be used in freezing temperatures. In addition this method invariably removes some surface asphalt and fines, and damage to the pavement joints- precursors for pot holes and pavement deterioration because of water percolation.

The other methods identified in the literature above are used on a very limited and on special circumstances. Most Department of Transportation and other agencies prescribe one of their preferred methods. Caltrans predominately prescribes grinding (abrasion methodology) as the other two widely used methods generate a large amount of waste and contribute to the degradation of the environment from sand impregnated with impurities captured during the sand blasting process and from contaminated water resulting from water blasting operations.

2. Laser technology

2.1 Theoretical background

To the best of our knowledge we do not know of any research that has been done for *commercial and workable* laser applications that reduce the costs or any research that is currently being conducted to make substantial improvements in performance and economics as outlined in this problem statement for pavements. Similar technology *concept* is used to ablate paint from military airplanes. However the laser paint ablation operations for aircraft have very specific issues and parameters which are very different from road pavements, such as type of substrate (aluminum, metal or composites), thermal conductivity and thermal diffusivity, extensive electronics, type of laser used (because the energy is quantized and is laser specific; therefore, a laser with a certain specific wavelength cannot have universal applications).

A laser imparts energy to the underlying material (stripe) and the energy is absorbed. At low laser flux material the material gets heated by the absorbed energy and it evaporates or sublimates. The material is not burned. At high flux the air is ionized and plasma is created. Use of plasma for road markings removal needs to be researched for its effects on the markings and its impact on substrate as a separate research project and that research is not within the scope and results of the reported research. The principal of laser removal of materials is as follows. The depth to which the energy is absorbed and the depth of the materials to be removed depends upon (1) the optical properties of the material to be removed (2) laser wave length and (3) pulse length- from milliseconds to femtoseconds. The total mass ablated per laser pulse is called ablation rate.

Two types of lasers are widely used CO2 and ND: YAG. CO2 lasers use CO2 as lasing medium. They emit a wavelength of 10.64 microns in the far infrared region. CO2 lasers are absorbed by organic materials such as paint, plastics, glass, fabrics and acrylics. Striping, organic material can be paint or thermoplastic and is defined in MUTCD (Manual of Uniform Traffic Control Devices), Title 23 CFR part 655. Most regulations dictate the chemical formulations to withstand traffic, weather, oils, resistance to weathering in cold climates, resistance to chains on tires etc.

ND: YAG lasers use Neodymium (ND) in a crystal with yttrium aluminum (YAG) to produce light. ND: YAG lasers emit a wavelength of 1.64 microns near infrared. These lasers have a small wavelength compared to CO2 lasers and are primarily used on metals and cannot be absorbed by organics materials. ND: YAG work well for engraving, welding, cutting, and drilling metals. Metals are reflective and CO2 lasers cannot penetrate the metal. The ND; YAG have a smaller wavelength and the light simply passes through and is not absorbed. Other differences are thermal efficiency, heat transfer, and maximum power output.

2.2 Laboratory tests and results for ablation of paint stripe from asphalt substrate

A lab prototype has been developed and the capability of laser-based paint ablation has been tested with the independent contractor in Mukilteo, Washington. The testing has been performed under three different powers and speeds. Standard yellow latex enamel paint was used on 0.5”x 6”. The lab prototype has the following parts/settings: Ti100, Motion FHFL50, Lens FLA200, Spot size= 290 um, Depth of Focus= 5mm. Various scan speeds were demonstrated at 100 W of laser power to show how much paint was removed at different speeds. The speeds listed in Table 1 refer to the scan speed of the galvo-mirrors moving back and forth across the material surface in the 0.5" strip width.

Table 1: Ablation rates and quality

Speed , ips	**Cycle Time, sec**	**Removal rate**	**Comment**
200	5.34	0.56 sqr. in./sec removal rate	Incomplete ablation(large rocks still have paint)
150	6.83	0.44 sqr. in./sec removal rate	Almost complete ablation
100	9.86	0 .3 sqr.in./sec removal rate	Complete ablation

The photo of the resulted ablation at different powers and respectively speeds shown In Fig. 4 demonstrates the quality of the process for a very rough (recycled piece) of asphalt. The photo is taken from different perspectives and mimics the view to the real road stripe as seen by a driver. As it can be observed, there is no ghost line causing driver distraction.

We have also contacted an independent contractor in California, Roseville who has been researching the idea of using the laser for marking removal. The company has provided own calculations of the cost of the technology in use and an estimate of the laser-based technology.

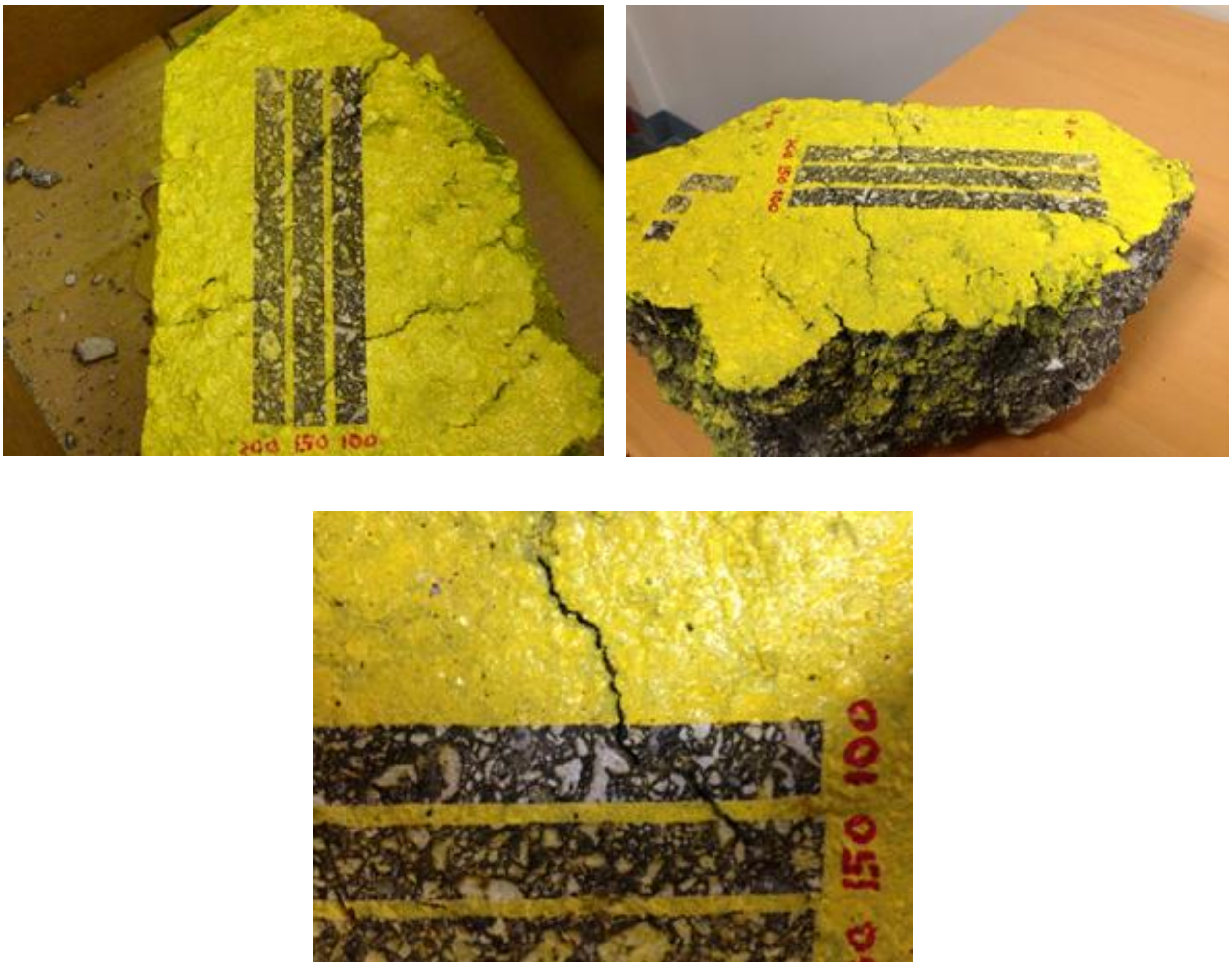


Fig.4. Ablation results under different power/speed levels shown from different angles and distances

The current cost of the equipment solely is about $1M. The company has confirmed that substantial damage is made to the surface of the asphalt grinding, and that usually the surface is to be sealed afterwards. The cost of that process sometimes is higher than that of grinding itself.

Grinding drums are to be replaced frequently (per 100 miles), and the disposal is hazardous. Although the cost of a packaged and installed laser-based system can be expected as high as $1.6M, it still would save about $100K per year for the contractor in disposal costs alone. The technology will allow for modifying the current approach of lane transition and marking which will reduce the labor and speed up the process, which in turn would increase the safety due to the impact of lane closure and re-routing. Actually, the potential total savings are very significant under our train approach as discussed below. A comprehensive cost/performance analysis is provided further in this document.

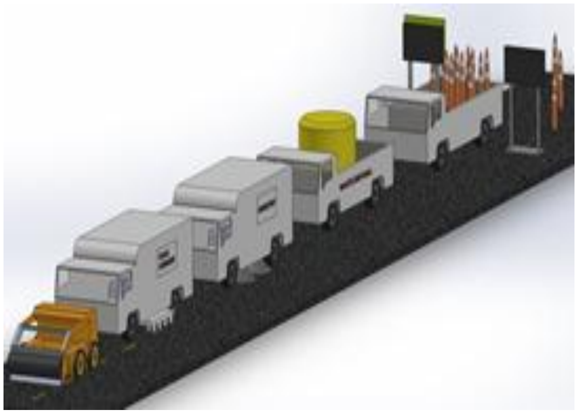
2.3 Discussion on the laser technology

Described below are the current method used and the proposed laser system. The current methods generally involve three phases and are a mob/ demob/mob operations. Laser system by contrast is a continuous operation yielding numerous advantages to the agency and the road consumers. Among them are:

1. No ghost lines.
2. User convenience.
3. Fewer traffic delays.
4. Environmentally friendly operation.
5. Avoidance of injuries and fatalities.
6. Shortened construction phase.
7. Fewer equipment breakdown delays.
8. No pavement damage.
9. No repairs necessary (slurry) of damaged pavement.
10. Overall savings to the agency, because of absent or minimal contributory costs of items 1-9.

To demonstrate the significant differences we present a pictorial depiction the current methods of road marking and proposed train method using laser systems. The pictorial presentation assumes a long stretch of a road. As each project is different and constructed by different contractors using different approaches the pictorial depiction is not exact but generally holds true for road marking operations

The current method has three distinct phases: (a) Removal operations (b) Inspection and repair of pavement which may have resulted from abrasion/grinding operations and (c) Striping operations.



Phase (a) equipment and sequence

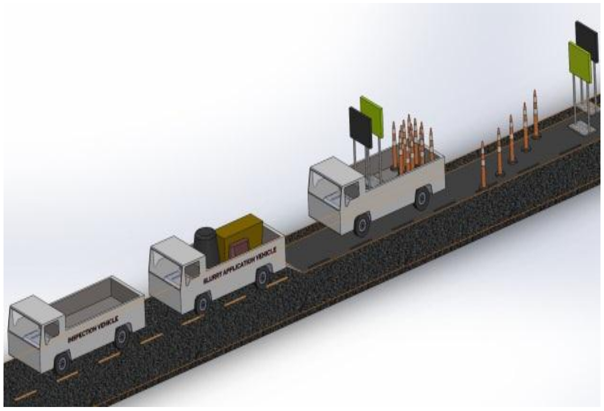
Marker removal equipment.

Fig.5 Phase a) of the current modus operandi.

A significant operation – addressing ghost stripe is not shown for reasons of clarity. For example CALTRANS the standard special provisions provide use of temporary tape (if the stripe line is moved) to minimize "visual distraction of ground off pavement marking ghost lines in low light conditions" (http://www.workzonesafety.org/standards_practices/record/6433).

Phase (a) of current method is shown in Fig.5. Under this phase, markers are removed, followed by a sweeper. The grinding truck follows the sweeper after the sweeper has collected the markers. Disposal drums/roll offs are also needed to dispose off the the ground stripe residue. Traffic safety is an important isssue and therefore a traffic control truck carries with it traffic control delineators, cones etc.

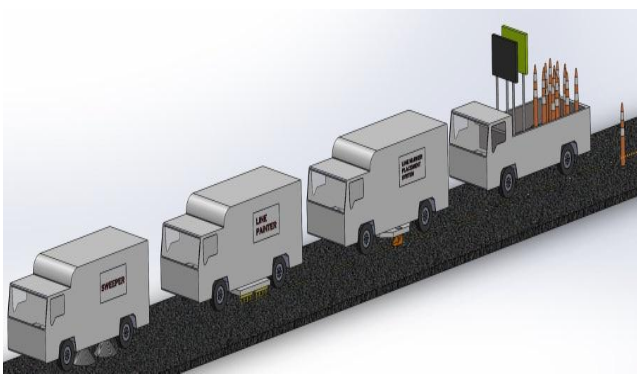
Phase (b) is represented in Fig.6. Invariably after grinding operations generally a visual inspection is conducted to determine if there has been damage to the pavement. In the event the pavement is damaged then remedial operations are instituted such as slurry over the damaged areas.



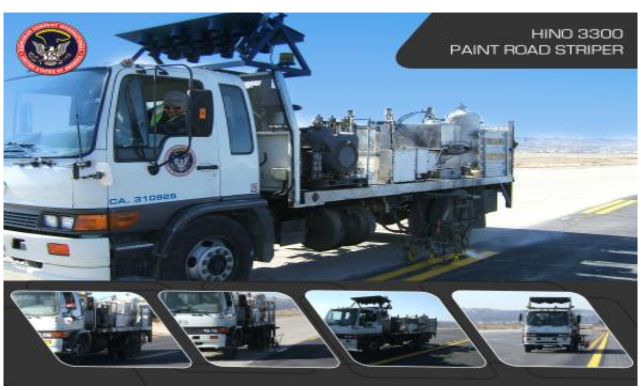
Phase b) equipment and sequence   Traffic control truck

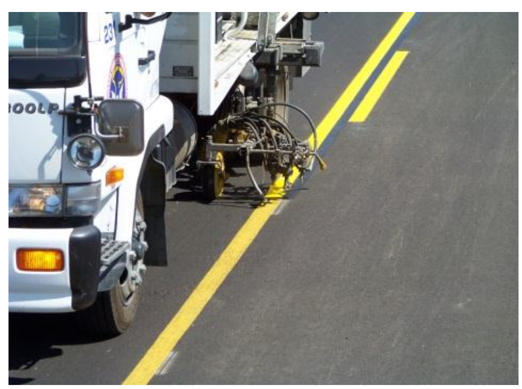
Fig.6 Phase b) of the current modus operandi

Phase (c) is the striping operations before the roadway is opened to traffic. It is represented in Fig.7



Equipment and sequence   Installation of markers





Striping

Fig.7. Phase c) of the current modus operandi

The proposed laser system allows for train operation as shown on Fig.8.

Fig.8. Future laser-based train system

3 Paint stripe removal: cost comparison of laser, grinding, and other methods

The cost estimation was done based on the data provided by the Sierra Traffic Markings, Inc. contractor who had conducted numerous traffic stripes removal for DOTs. The data provided by this company is included in the Appendix. The detailed estimated of the laser equipment was based on some assumptions, because this kind of equipment has not been made till now. The rates of materials, labor, fuel, and oil were used from the recent rate of Nevada.

3.1 Cost estimation of stripe removal using laser equipment

To prepare a preliminary cost of laser removal method, the following assumptions were made:

1. The investment cost of Laser removal equipment is $1,600,000
2. The production rate of the equipment for asphalt pavement is 0.44 square inches /sec using single 100 W laser-tube. One laser-tube can remove 0.5 inch width of stripe. So to remove 4 inches stripe width, eight 100 W laser tubes will be used in the equipment.

Production Rate of the laser removal in the lab, P.R. = 0.44 square inches/sec for each laser tube

Considering eight laser tubes,

Production Rate of the laser removal equipment = 0.44 square inches/ sec x 8 = 3.52 square inches / sec

PR of laser removal equipment = (3.52 square inches/sec 4 in.) = 0.88 line-in/sec

= 0.88*60*60/12 line ft/hr

= 264 ft./ hr

This production rate is calculated based on the laboratory work. However during the stripe removal process on the road, if this laser equipment is used on the broken stripe lines, then the production rate can be increased by double. Therefore for the cost estimation purpose the production rate of the laser equipment is considered as 528 ft/hr.

3.1.1 Ownership Cost

Investment Cost of Laser removal truck = $1,600,000. The following assumptions are made for the laser equipment

1. The life of the equipment is at least 15 years
2. The laser truck is of 160 hp engine and since vehicle runs on paved road with slower speed, the actual fuel consumption is 25% of the total fuel consuming capacity (0.06 gal/hp-hr)
3. The truck operates with gasoline
4. The salvage value of the equipment is $50,000
5. The annual interest rate is 5%
6. The equipment will run for 223 working days with 8 hours per day

Using Engineering Economics' Capital Recovery equation,

Ownership Cost (OC) of the laser removal equipment

$$OC = Purchase\ Cost\ \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] - Salvage\ value\left[\frac{i}{(1+i)^n - 1}\right]$$

$$= \$1{,}600{,}000\ \left[\frac{0.05(1+0.05)^{15}}{(1+0.05)^{15} - 1}\right] - \$50{,}000\left[\frac{0.05}{(1+0.05)^{15} - 1}\right]$$

$$= \$1{,}600{,}000\ \left[\frac{0.05 \text{ x } 2.08}{2.08 - 1}\right] - \$50{,}000\left[\frac{0.05}{2.08 - 1}\right]$$

$= \$154{,}074 - \$2{,}315$

$= \$151{,}759$ per year

Total hours the equipment will be running per year = 223 days x 8 hours/day= 1,784 hours/year

Ownership Cost (OC) per hour = $151,759/ 1,784 hours

= $85.07/ hour

3.1.2 Operating Cost

3.1.2.1 *Maintenance and repair cost*

The annual cost of maintenance and repairs is generally expressed as a percentage of the straight-line depreciation costs. Let us assume 80% of the depreciation cost

$$M\&R\ Cost = 80\%\ [(\$1{,}600{,}000 - \$50{,}000)/15 years]$$

$$= \$103{,}333 \text{ per year}$$

$$= \$103{,}333\ /\ 1{,}784 \text{ hours} \qquad = \$57.90/\text{ hr}$$

3.1.2.2 Fuel consumption cost

The amount of fuel consumption for gasoline engine is given by the following formula

$$Gasoline\ consumption\ per\ hour$$

$$= (time\ factor)\ x\ (enginer\ factor) x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp - hr}$$

This gasoline consumption equation is generally used for the truck moving in the normal speed of about 30 to 50 mph. However for the slower movement vehicles, it is assume that 50% less gasoline will be consumed. Therefore the modified equation will be

$$Gasoline\ consumption\ per\ hour$$

$$= 0.50\ x\ (time\ factor)\ x\ (enginer\ factor)\ x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp - hr}$$

It is assumed that time factor = 0.75 and engine factor = 0.60. The horsepower of the dump truck is 200 hp.

$$Gasoline\ consumption\ per\ hour = 0.5\ x\ (0.75)\ x\ (0.60)\ x\ 200\ hp\ x\ 0.06 \frac{gal}{hp - hr}$$

$$= 2.7\ gal/hr$$

Cost of gasoline = \$3.75/ gal x 2.7 gal/hr = \$10.12/hr

3.1.2.3 Lubricating oil consumption cost

The amount of lubricating oil consumed by an engine is given by the following formula

$$Oil\ consumption\ per\ hour = \frac{HP\ x\ (time\ factor) x\ (engine\ factor)\ x\ 0.006}{7.4} + \frac{c}{t}\ gallon\ per\ hour$$

Where c = Capacity of crankcase and t = time between the oil changes

The crankcase capacity of the truck is 4 gallons and time between oil changes is 100 hours.

Therefore,

$$Oil\ consumption\ per\ hour = \frac{200\ hp\ x\ (0.75) x\ (0.60)\ x\ 0.006}{7.4} + \frac{4}{100}\ gallon\ per\ hour$$

= 0.11 gal/hr

Cost of oil per hour = 0.11 gal/hr x \$9.00/gal = \$0.99/hr

3.1.2.4 Rubber Tires cost

For the laser stripe removal truck, the tires need to be replaced every 2 years. Therefore the cost of new sets of tires should be estimated for the life of the equipment. Let us assume that the cost of tires is about \$4,500 for this truck and these tires will last 2 years. Therefore,

Cost of tires per hour = \$4,500 / (2 x 1,784 hours) =\$1.26 per hour

The tire repair cost is generally taken as 15% of its yearly depreciation

Tire repair cost per hour = \$1.26 x 0.15 = \$0.19/ hour

Total cost of tires and their repair = \$1.26 + \$0.19 =\$1.45/ hour

3.1.2.5 Operator and Labor Cost

Let us assume that two labors and one equipment operator are needed to operate this machine. The cost of equipment operator is assumed to be $50/hour and labor is $35/hour.

Hourly operator and labor cost = $50 + 2 x $35 =$120/hour

Total operating and maintenance cost of the truck = $57.90 + $10.12 + $0.99 + $1.45 +$120

= $190.46/ hour.

3.1.2.6 Cost of Laser tube replacement

It is assumed 8 laser tubes installed in the truck will last only for 2 years. The cost of each laser tube is estimated as $100,000.

Cost of laser tube replacement per hour = 8 x $100,000 / (2 x 1,734 hours) =$230.68 /hour

Total ownership, operating and maintenance, and laser tube replacement cost

= $85.07 + $190.46 +$230.68 =$506.21/ hour

Removal cost of stripe per lane mile by Laser (Direct Cost)

Production rate = 528 ft / hour

Time to remove 1 line-mile stripe (5,280 ft) = 5,280 ft / 528 ft/ hr = 10 hours

Cost to remove 1 line-mile stripe = 10 hours x $506.21/ hr = $5,062.

Generally in the cost estimate, the direct cost is about 80% of the total estimated cost and the rest of the 20% is indirect cost. Therefore the total cost of stripe removal per lane mile by Laser equipment is calculated as;

Total Removal Cost by using Laser Equipment = $5,062 / 0.80 = $6,327.50/ per lane mile.

3.2 Cost estimation of stripe removal using grinding equipment

The Sierra Traffic Marking Inc. provided approximate costs of grinding equipment to remove striping lines. To prepare a preliminary cost of grinding, the following assumptions were made:

1. The investment cost of Striping removal truck is \$750,000
2. The investment cost of sweeper truck is \$200,000
3. The production rate of the grinding equipment (Tungsten Carbide grinding) set is 23.6 ft/minute (NCHRP 2013, p. 11) that is $\left[\frac{23.6*60}{5280}\right]$=0.268 mile per hour
4. The cost of grinding drum is \$2,500 and the life of that drum is for 100 miles; so the cost of drum in per hour basis is $\left[\frac{\$2,500*\ 0.268}{100}\right]$ = \$6.7 per hour.

3.2.1 Ownership Cost

Investment Cost of Striping removal and sweeping truck = \$750,000 + \$200,000 = \$950,000. The following assumptions are made for the both of the trucks:

1. The life of the equipment is at least 15 years.
2. The striping removal truck is of 300 hp and sweeping truck is of 200 hp engine.
3. The truck operates with gasoline.
4. The salvage value of both trucks is \$50,000.
5. The annual interest rate is 5%.
6. The equipment will run for 223 working days with 8 hours per day.

Using Engineering Economics' Capital Recovery equation,

Ownership Cost (OC) of the laser removal equipment

$$OC = Purchase\ Cost\ \left[\frac{i(1+i)^n}{(1+i)^n-1}\right] - Salvage\ value\left[\frac{i}{(1+i)^n-1}\right]$$

$$= \$950{,}000\ \left[\frac{0.05(1+0.05)^{15}}{(1+0.05)^{15}-1}\right] - \$100{,}000\left[\frac{0.05}{(1+0.05)^{15}-1}\right]$$

$$= \$950{,}000\ \left[\frac{0.05 \text{ x } 2.08}{2.08-1}\right] - \$100{,}000\left[\frac{0.05}{2.08-1}\right]$$

$$= \$91{,}481.48 - \$4{,}629.63$$

$$= \$86{,}851 \text{ per year}$$

Total hours both the equipment will be running per year = 223 days x 8 hours/day= 1,784 hours/year

Ownership Cost of both trucks (OC) per hour = $86,851/ 1,784 hours

= $48.68/ hour.

3.2.2 Operating Cost of Striping removal and Sweeping trucks:

3.2.2.1 Maintenance and repair cost of Striping removal and Sweeping trucks

The annual cost of maintenance and repairs is generally expressed as a percentage of the straight-line depreciation costs. Let us assume 80% of the depreciation cost

$$M\&R\ Cost = 80\%\ [(\$950{,}000 - \$100{,}000)/15 years]$$

$$= \$45{,}333 \text{ per year}$$

$$= \$45{,}333\ /\ 1{,}784 \text{ hours} \qquad = \$25.41/\text{ hour.}$$

3.2.2.2 Fuel consumption cost of Striping removal truck

The amount of fuel consumption for gasoline engine is given by the following formula

$$Gasoline\ consumption\ per\ hour$$
$$= (time\ factor)\ x\ (enginer\ factor) x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp - hr}$$

This gasoline consumption equation is generally used for the truck moving in the normal speed of about 30 to 50 mph. However for the slower movement vehicles, it is assume that 25% less gasoline will be consumed. Therefore the modified equation will be

$$Gasoline\ consumption\ per\ hour =$$
$$0.75\ x\ (time\ factor)\ x\ (enginer\ factor)\ x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp-hr}.$$

It is assumed that time factor = 0.75 and engine factor = 0.60. The horsepower of the dump truck is 300 hp.

$Gasoline\ consumption\ per\ hour = 0.75\ x\ (0.75)\ x\ (0.60)\ x\ 300\ hp\ x\ 0.06 \frac{gal}{hp-hr}. =$

$6.08\ gal/hr.$

Cost of gasoline = \$3.75/ gal x 6.08 gal/hr <u>= \$22.80 /hr.</u>

3.2.2.3 Fuel consumption cost of Sweeping truck

The amount of fuel consumption for gasoline engine is given by the following formula

$Gasoline\ consumption\ per\ hour$

$$= (time\ factor)\ x\ (enginer\ factor) x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp - hr}$$

This gasoline consumption equation is generally used for the truck moving in the normal speed of about 30 to 50 mph. However for the slower movement vehicles, it is assume that 25% less gasoline will be consumed. Therefore the modified equation will be

$Gasoline\ consumption\ per\ hour$

$$= 0.75\ x\ (time\ factor)\ x\ (enginer\ factor)\ x\ Horse\ Power\ x\ 0.06 \frac{gal}{hp - hr}$$

It is assumed that time factor = 0.75 and engine factor = 0.60. The horsepower of the dump truck is 200 hp.

$$Gasoline\ consumption\ per\ hour = 0.75\ x\ (0.75)\ x\ (0.60)\ x\ 200\ hp\ x\ 0.06 \frac{gal}{hp - hr}$$

$$= 4.05\ gal/hr$$

Cost of gasoline = \$3.75/ gal x 4.05 gal/hr = \$15.19 /hr

3.2.2.4 Lubricating Oil consumption cost of Striping removal truck

The amount of lubricating oil consumed by an engine is given by the following formula

$Oil\ consumption\ per\ hour$

$$= \frac{HP\ x\ (time\ factor) x\ (engine\ factor)\ x\ 0.006}{7.4} + \frac{c}{t}\ gallon\ per\ hour$$

Where c = Capacity of crankcase and t = time between the oil changes

The crankcase capacity of the truck is 4 gallons and time between oil changes is 100 hours.

Therefore,

$$Oil\ consumption\ per\ hour = \frac{300\ hp\ x\ (0.75) x\ (0.60)\ x\ 0.006}{7.4} + \frac{4}{100}\ gallon\ per\ hour$$

= 0.15 gal/hr

Cost of oil per hour = 0.15 gal/hr x $9.00/gal = $1.35 /hr

3.2.2.5 Lubricating Oil consumption cost of Sweeping truck

The amount of lubricating oil consumed by an engine is given by the following formula

$$Oil\ consumption\ per\ hour = \frac{HP\ x\ (time\ factor) x\ (engine\ factor)\ x\ 0.006}{7.4} + \frac{c}{t}\ gallon\ per\ hour$$

Where c = Capacity of crankcase and t = time between the oil changes

The crankcase capacity of the truck is 4 gallons and time between oil changes is 100 hours.

Therefore,

$$Oil\ consumption\ per\ hour = \frac{200\ hp\ x\ (0.75) x\ (0.60)\ x\ 0.006}{7.4} + \frac{4}{100}\ gallon\ per\ hour$$

= 0.11 gal/hr

Cost of oil per hour = 0.11 gal/hr x $9.00/gal = $0.99 /hr.

3.2.3 Rubber Tires cost of Striping removal and sweeping truck

For both of the trucks, the tires need to be replaced every 2 years. Therefore the cost of new sets of tires should be estimated for the life of the equipment. Let us assume that the cost of tires is about $4,500 for each of the trucks and these tires will last 2 years. Therefore,

Cost of tires per hour = $4,500 / 2 x 1,784 hours =$1.26 per hour

The tire repair cost is generally taken as 15% of its yearly depreciation

Tire repair cost per hour = $1.26 x 0.15 = $0.19/ hour

Total cost of tires and their repair for both of the trucks = 2*($1.26 + $0.19) =$2.90 /hour.

3.2.4 Operator and Labor Cost for Striping removal and sweeping trucks

Let us assume that two labors and one equipment operator are needed to operate each of the trucks. The cost of equipment operator is assumed to be $50/hour and labor is $35/hour.

Hourly operator and labor cost = 2*($50 + 2 x $35) =$240 /hour

3.2.5 Cost of grinding drum replacement

It is assumed the striping removal truck uses Carbide grinding drum and it will last only for 100 miles of operation. The cost of each grinding drum is estimated as $2,500

Cost of grinding drum replacement = $6.7 /hour (as calculated above)

3.2.6 Cost of removed paint containment and disposal

Assuming the cost of containment on jobsite, disposal of white and yellow paint removed are $1,000 per containment, $500 for white paint disposal, and $250 for yellow color (55 gal.) disposal. It is also assumed that the containment is filled up at every 300 hours of operation. Moreover, the white and yellow color striping paint filled up at every 300 and 600 hour of operation respectively. Therefore the total cost of paint disposal is $\frac{\$1,500}{300\ hr} + \frac{\$250}{600}$ = $5.42 per hour

Total operating and maintenance cost of the truck = $25.41 + ($22.80 + $15.19) + ($1.35 + $0.99) + +$2.90 +$240 + $6.7 + $5.42

= \$320.76/ hour

Total ownership, operating and maintenance, and laser tube replacement cost

= \$48.68 + \$320.76 =\$369.44/ hour

Removal cost of stripe per line mile by grinding method

Production rate = 0.268 mile / hour (Calculation shown above)

Time to remove 1 line-mile stripe	= 1 /0.268 mile / hour	= 3.73 hours
Cost to remove 1 line-mile stripe	= 3.73 hours x \$369.44/ hr	= \$1,378.01 per line-mile
Adding 20% indirect costs	=\$1,378.01/ 0.8	=\$1,722.50 per line-mile.

Removal costs of stripe per line mile by grinding method ==\$1,722.50 per line-mile.

3.3 **Comparison of stripe removal methods based on literature review**.

A study conducted by Washington State Department of Transportation (WSDOT) described three pavement marking removal methods: grinding, hydro-blasting, and shot-blasting (FHWA 2006). The grinding machine used to remove stripe can be sub-classified into rotary and drum type. The drum grinding machines are more efficient than rotary type, because they are capable of removing any type of line or marking on asphalt as well as concrete pavements. However, they can leave a 'ghost stripe.' The second paint removal method is Hydro-blasting; this method uses high pressure water (34,000 to 40,000 psi) to remove striping from the road surface. This method is capable of cleaning all kinds of striping paints (striping paints and thermoplastics) from asphalt and concrete pavements. Different sizes of hydro-blasting machines are available in practice. One of the pros of hydro-blasting machines are they do less damage on the pavement with a clean surface left behind to do restriping immediately after. These machines can remove paints at a speed of up to 7,500 linear feet per hour. The third paint removal method is shot blasting machine and it consists metal beads or shot propelled at high speed to remove striping from the pavement. The shot blasting method can remove striping from both asphalt and concrete surfaces. This machine comes with a vacuum; because the shot machines use vacuum to clean up immediately after it hits the pavement. This method is not effective over new pavements, wet pavements, and to remove thermoplastics and tapes. The stripe removal rate of these machines is about 1,400 linear feet per hour.

This study also explained the factors affecting paint removal production rate with various machines. Basically, the production rate of machines depends upon pavement type, weather, surface condition, and machine dependability. The hot mix asphalt (HMA) pavements are softer than concrete pavements; so, the striping removal production rate using grinding machines is faster on HMA pavements as compared to concrete pavements. For hydro-blasting machines, the production rate on HMA and concrete pavements is comparable and the production rate is about 3,000 linear feet per hour; the production rate increases in dense graded pavement. One of the disadvantages of operating the grinding machines is having more mechanical problems as compared to other machines. For grinding machines, it takes more time to remove striping on the denser pavements. For shot-blaster machines, they take more time on rough pavements to completely remove the paints; and in wet condition, the machine cannot operate.

Oregon Department of Transportation found that hydro blasting and sand blasting methods are more efficient in removing striping than grinding and soda blasting methods (Haas 2001). The disadvantages of hydro blasting are that water can freeze at low temperature creating problems on the pavement and this method can even remove layer of asphalt binder that can lead to water infiltration inside the pavement (Pike and Miles 2013). The disadvantage of sand blasting is it produces byproducts as sand, striping materials, and pavement materials that can lead to environmental issues. The advantages of the soda blasting are that it leaves little scarring on the asphalt pavement and it is also environmental friendly. The disadvantage of this method is that it requires cleaning up the residual by broom or vacuum after the equipment was used (Haas 2001). The advantage of grinding method is that the removal rate is faster than soda blasting. The disadvantage of this method is it scarred the pavement more and left residue of asphalt, aggregate and paint of the pavement surface.

The chemical method uses chemicals over the striping line and then washed off with pressure (Pike and Miles 2013). Generally, for a thinner striping (0.01-0.02 in. thick) one application of chemical is used and more applications for thicker striping lines. The chemical method is suitable for a smooth surface of both asphalt and concrete pavements. A care should be taken with strong chemicals for not to damage specially the asphalt pavements. After the chemical application and then washed off, a vacuum is required to clean up the roadway. The disadvantage of this method is the environmental issue.

The laser removal method is still under experiment to be used in the field (Pike and Miles 2013). This method does not make contact to the road surface, and so, there is little or no wear on the pavement. Therefore, it reduces maintenance cost, pavement degradation, and environmental issues. The laser method is comparatively slow, and requires more time to remove the striping completely. The advantages of this method are that the pavement surface will not be damaged, the residuals will not be left to clean and it is also environmental friendly.

The masking method is basically covering the striping with something else to hide its presence (Pike and Miles 2013). The advantages of this method are no damage to the road surface and reusing the hidden stripes easily later on when required. However, it is expensive, difficult to match the color of masking to the road surface, suitable for temporary purposes, and only tape can be used. Based on the literature review, the pro and cons of these methods are outlined in Table 2.

Table 2. Comparison of Various Stripe Removal Methods (Hass, 2001; FHWA, 2006; Berg and Johnson, 2009; Pike and Miles, 2013)

Methods	Advantages	Disadvantages	Environmental Hazards
Grinding	High removal speed, pavement can be repainted immediately	Pavement degradation, Left shadow lines on the pavement, pavement damage	Dust, noise, airborne silica, storm water contamination
Hydro-Blasting	High removal speed, No shadow line, no pavement damage	Pavement remain wet, safety hazard during low temperature	Probable lead contaminants, water contamination
Soda Blasting	No shadow line, no pavement damage	Slow removal speed, safety hazard due to dust	Dust and noise hazard
Chemical-based	No pavement damage	Needs vacuum to clean the road, impact of chemical in pavement	Chemical contamination of runoff water
Laser-based	No pavement damage, no shadow line	Slow removal rate	None

3.4 Cost comparison discussion

The research team has estimated the cost of stripe removal by use of laser and grinding machines based on the contractors' data and some other assumptions. The estimated cost data of the laser equipment is hard to verify as this type of equipment has not been developed. Table 3 shows the estimated cost of stripe removal of various methods. The cost derived from literature review were converted to 2014 base cost using Engineering News Record (ENR) construction cost indexes. Table shows that laser based removal method is 3.7 times more expensive than grinding method. However the contactor who provided this data mentioned that if laser based removal can be used then there will be saving of at least $100,000 per year from the recovery and disposal cost. Also the cost of the laser is very high, if this cost can be reduced then the laser based removal method will be affordable. Reviewing the removal rate of the laser equipment, it seems the removal rate is very slow in compare to other removal methods. Therefore if the removal speed can be increased then the cost to remove the stripes by laser can be reduced. Verifying the calculated cost of grinding method with the cost derived from the literature review, it seems very reasonable.

The direct cost of laser removal process seems high. However if the lifecycle cost of the entire stripe removal process is considered, the benefit of using laser removal will outweigh the benefit of other methods. There are some other costs saving associated with laser based method, for example, saving from environmental impacts, saving from pavement damage, saving from reduced crashes, savings from noise and dust hazards, and savings from recovery and disposal of paints. These cost savings are very difficult to calculate to show that laser base method will be more cost effective than other methods.

Table 3. Cost Comparison of Various Stripe Removal Methods

S.N.	Stripe Removal Methods	Calculated Cost ($/Line-Mile)	Cost in 2014 Collected from Literature ($/ Line-Mile)
1	Laser Removal	$6,327.50	-
2	Grinding	$1,722.50	$2,210
3	Hydro Blasting	-	$3,039
4	Sand Blasting	-	$3,481

The direct cost of laser removal process seems high. However if the lifecycle cost of the entire stripe removal process is considered, the benefit of using laser removal will outweigh the benefit of other methods. There are some other costs saving associated with laser based method, for example, saving from environmental impacts, saving from pavement damage, saving from reduced crashes, savings from noise and dust hazards, and savings from recovery and disposal of paints. These cost savings are very difficult to calculate to show that laser base method will be more cost effective than other methods.

4 Implemented schedule and deliverables

Schedule: The project was completed on schedule.

Task 1: Literature Review

Extensive and pertinent review of field applications of CO2 lasers as applied to ablation of paint used as road markings was conducted. Included in the review were potential vendors with capability to conduct tests

Task 2: Lab testing of the proposed application

Real life asphalt samples were obtained and subject to the protocol developed by the team to ascertain the objectives of the project. The lab test results are included in this report.

Task 3: Report preparation

This draft report is being submitted to NDOT. The report can be modified in accordance with the NDOT comments and recommendations.

Acknowledgements

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APPENDIX

SIERRA
TRAFFIC MARKINGS, INC.

3/1/2014

I Ron Johnson, owner of Sierra Traffic Markings, Inc. and Sierra Striping, Inc. of Roseville, California have been researching the idea of using the laser removal process for striping removal and am definitely interested in pursuing the use of this technology which was introduced to me in 2013. Our current process is by scarifying (grinding) the traffic stripes which has always been a very costly process in terms of equipment, maintenance, recovery, and disposal.

For instance:

1. Striping removal truck	$750,000
2. Sweeper truck	$200,000 (or subcontract at $140 per hour)
3. Replacement grinding drums	$2500 ea. (which lasts approx. 100 miles)
4. Containment on jobsite	$1000 per container fill up.
5. Disposal	$500 per container
6. Yellow Disposal (hazardous)	$250 per 55 gallon drum

I have also been required many times to seal the asphalt surface due to the damage to the surface of the asphalt caused from the grinding method which is always very costly, in many cases more that the line removal itself.

Therefore for these reasons I have done my own studies on the laser removal process and have estimated that the cost of a new laser removal truck at $1.600,000 would pay for itself in about four years depending on the amount of work. Just in the recovery and disposal I could save roughly $100,000 per year based on my last few years of line removal. The life of a stripe removal grinder truck is very short, approximately eight years due to the nature of the removal process. I feel a laser truck should last at least 15 years. The constant break downs of a striping removal grinder truck is very costly with the high costs of labor especially on prevailing wage projects. I am very interested in seeing this type of removal introduced to our striping industry because of the cost savings and the environmental impact to lessen the amount of striping removal grindings which are disposed of in our landfill daily across the country.

Furthermore the laser paint removal method will allow us to modify our current methodology of lane transition road marking. We can foresee using a train style continuous operation system as opposed to a segmented system in which we are currently using. This would greatly reduce labor costs and limit the time we are actually on the roadway which in turn greatly reduces risk as regards to safety for the work force and the impact on traffic as far as lane closure hours. Therefore the result is considerable savings to our company overall so we would be very interested in the investment for the laser paint striping removal truck once it is introduced to the striping market.

Sincerely,
X.
Ron W. Johnson COO

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