

Automated Roadway Pavement Marker Placement System

Final Project Report

August 2011

FHWA-HIF-11-048

HIGHWAYS FOR LIFE

Accelerating Innovation for the American Driving Experience.



U.S. Department of Transportation
Federal Highway Administration

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16. Abstract The Federal Highway Administration awarded a \$405,560 grant to Stay Alert Safety Services, Inc. of North Carolina to refine and test its automated pavement marker placement system under the Highways for LIFE Technology Partnerships Program. This report describes Phase 2 of the project, which involved making several modifications and upgrades to the system, evaluating its performance on a raised pavement marker installation contract, and comparing it to traditional manual methods of marker placement. The evaluation showed that the system performed well during its first full-scale application. It displayed several advantages over manual methods of marker placement: improved safety by eliminating the need for a laborer to work near live traffic and with high-temperature bitumen, consistent adhesive and marker placement, and cost savings from one fewer worker and potentially higher production rates.			
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Executive Summary

In 2007, the Federal Highway Administration awarded a grant to Stay Alert Safety Services, Inc. of North Carolina to refine and test its automated pavement marker placement system under the Highways for LIFE Technology Partnerships Program. In traditional marker placement methods, a laborer works near live traffic and is exposed to high-temperature bitumen adhesive. The automated system replaces the laborer, eliminating possible injuries from these potential dangers. The purpose of the Technology Partnerships project was to improve the automated system's capabilities and evaluate its productivity in real-world applications.

The project was divided into two phases. In Phase 1, several of the machine's subsystems were redesigned and rebuilt, and in November 2008, an initial field test was performed. Based on the initial field test results, the project team concluded that the system design was technically sound and the system was ready for Phase 2, evaluation of applications in the real-world environment. In the beginning of Phase 2, several modifications were made to the system to improve its reliability and efficiency. In May 2011, the automated pavement marker placement system was used in its first full-scale application on an actual pavement marker installation contract. A few minor adjustments were made during the week of the installation, but by the end of the week the system was consistently performing well.

Evaluation of the system's production rates and comparison to traditional production rates proved that the system can place markers at a rate similar to the highest production rates under the traditional method. Therefore, the automated system not only improves safety by removing a laborer from exposure to live traffic and hot bitumen adhesive, but also provides cost savings from elimination of the laborer while still producing similar or better marker placement rates.

1. Introduction

In November 2007, the Federal Highway Administration awarded a \$405,560 grant to Stay Alert Safety Services, Inc. of North Carolina to refine and test its automated pavement marker placement system. The project, funded under the Highways for LIFE Technology Partnerships Program, was divided into two phases. The following were the objectives of Phase 1:

- Enhance the delivery subsystem, adhesive subsystem, control subsystem, and platform.
- Conduct initial field testing.

During the field test in November 2008, a few minor adjustments were made to improve the machine's performance and reliability. Phase 1 was considered complete on January 31, 2009. Details of the work completed in Phase 1 are described in the Phase 1 progress report in the appendix.

The objective of Phase 2 was to conduct full-scale field applications for real-world raised pavement marker (RPM) installation projects to evaluate the system's performance in the environment and conditions of its intended use. This final phase allowed the project team to further refine the system and maximize its production capabilities. This report describes the Phase 2 activities in the following sections: a) modifications made to the system since Phase 1, b) results of the field application performance evaluation, and c) comparisons to traditional manual methods of marker placement.

2. Modifications Made During Phase 2

Following completion of Phase 1, Detail Technologies Inc., the subcontractor hired to design and build the system, made several modifications to correct for issues experienced during the initial field tests as well as to enhance the machine's capabilities. The following summarizes the modifications to the machine's various components:

- **Delivery arm rotation cylinder.** Because the marker truck's orientation on the road may not always be perfectly parallel to the desired marker location, a rotation cylinder was added to the delivery arm. The rotation cylinder allows a marker's position to be rotated up to +/- 30 degrees. To prevent the cylinder from rotating until it is clear of the machine, a sensor and more programming code were added to the system. Additional code was written to automatically return the rotation cylinder to a "home" position parallel to the truck orientation.
- **Detachable magazine rack.** Because markers from different manufacturers come in different sizes, separate magazines need to be created for the various marker sizes. Only one set of magazines was made for the marker system prototype, but in Phase 2 the magazine rack was converted from permanently mounted to removable to accommodate the need to switch magazine racks. This conversion also required adding quick disconnects to the paddle cylinders and photo eye sensor for each magazine. The entire magazine rack can be detached in about 5 minutes.
- **Conveyor speed control.** A speed control was added to the conveyor belt, allowing flexibility to increase or decrease the speed at which the markers move along the conveyor belt.

- **New dogs for advancing markers along conveyor.** Because of the increased speed of the conveyor belt, the proximity switch for the two dogs attached to the conveyor belt could not detect the dogs and markers were not released. To solve this problem, the dogs were replaced with new dogs (figure 1) that have a solid, more detectable surface on the side that passes by the proximity switch.

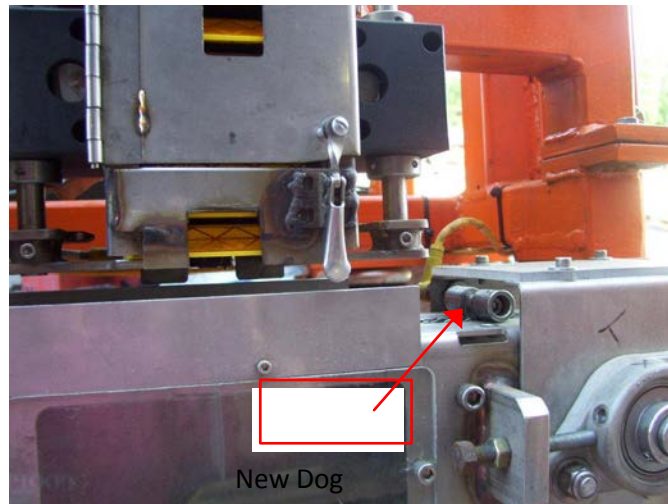


Figure 1. New dogs for conveyor belt.

- **Conveyor chain tensioner.** Because chains can become loose over time, a tensioner was added to the conveyor chain.
- **Conveyor box view panels.** Windows (figures 2 and 3) were added to the conveyor system box to provide the operator with a better view of the system.

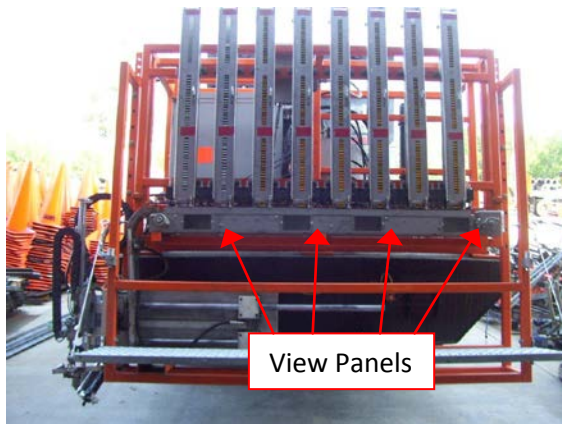


Figure 2. Conveyor box view panels.

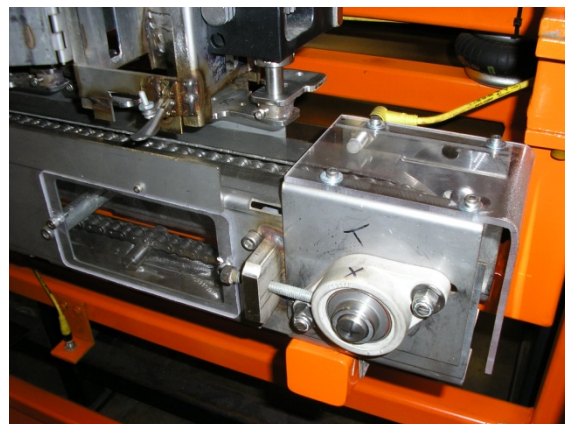


Figure 3. Closeup of view panel.

- **Conveyor box position adjustment.** Components were added to the conveyor system to allow the conveyor box to be adjusted left, right, forward, or backward.

- **Reversing conveyor direction.** A valve was added to the hydraulic system to allow the conveyor to be reversed so that a jammed marker could be removed easily. This is also a safety feature that is integrated into the control system.
- **Control panel view.** A panel view (figure 4) was added to the control panel to provide an operator interface. The operator can see every aspect of the machine function and make adjustments to programs. If an error occurs, the operator can quickly determine the cause and make corrections.



Figure 4. Control panel view.

- **Marker stack support/release paddles.** The paddles at the bottom of the marker magazines were originally attached to the paddle shaft with collars that bolted onto the shaft. However, these collars did not hold the paddles in position very well and markers became stuck at the bottom of the magazine. To solve this problem, all 32 paddles (two pairs for each magazine) were removed and, as shown in figure 5, each pair was welded together at an 85-degree angle with the rear paddle 0.5 inch (12.7 millimeters) higher than the front paddle.

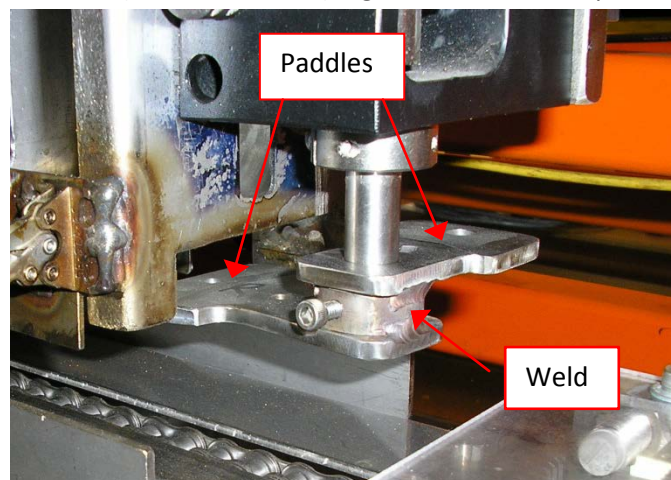


Figure 5. Welded marker paddles.

- **Magazine selector switch.** To allow an operator to install both white and yellow markers without getting out of the truck to reload magazines, a selector switch was added to the control

system and remote pendant to switch between magazines preloaded with different-color markers.

- **Marker chute speed damper.** A speed damper (figures 6 and 7) was added at the bottom of the marker delivery chute to reduce the speed of the marker as it comes out of the chute and prevent it from flying out of the delivery tray.

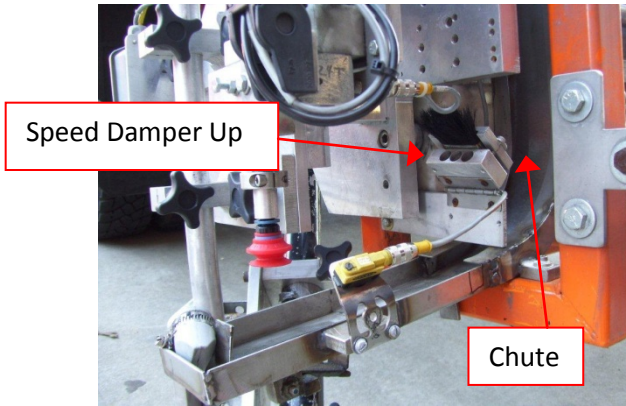


Figure 6. Speed damper in up position.

Figure 7. Speed damper in down position.

- **Safer transport position.** Because the frame of the marker system is relatively low to the ground and could be damaged if run into a curb or other low object, a hinge was placed on the forward portion of the frame. The system can be pivoted, raising it higher off the ground to allow for safe transport. Once rotated in the up-position, the system is held in place by a cable attached to the frame.



Figure 8. Transport position.

- **Synchronization with adhesive system.** During initial field tests, the automated marker placement system placed adhesive for only every other marker. After discussions with the manufacturer of the bitumen adhesive system, the project team identified the problem as a

timing issue with the adhesive system. The timer on the marker system's control panel was adjusted to match the proximity switch on the adhesive pot cylinder.

3. Field Application Performance Evaluation

In May 2011, the automated pavement marker placement system was used on its first full-scale contracted RPM installation project. The markers were placed on a four-lane section (two lanes in each direction) of U.S. Route 64 in North Carolina. The work began the week of May 9, and the project team was present the entire week to evaluate the machine's performance and provide any necessary troubleshooting. Production rates were recorded as part of the evaluation. This section discusses the results of each day's observations.

Monday, May 9, 2011: During about 4 hours of work, the operator successfully placed 356 markers. Before this day, the operator had received training on the system, but had never operated the system in the field. During the day, there were several short stops (1 to 10 minutes each) during which the operator successfully performed troubleshooting on his own. Troubleshooting included removing markers that jammed at the top of the chute, adjusting a sensor near the delivery tray, and resetting the delivery cycle from the control panel. When the system and operator were functioning at their peak performance, a marker was placed every 15 to 21 seconds. The time spent traveling the 80-foot (24.3-meter) spacing between RPMs was about 9 seconds. The remaining 6 to 12 seconds was the operator's performance time and the delivery arm's cycle time. The operator's performance time includes the time spent getting the system into position, extending the delivery arm (rotating the arm if necessary), placing the adhesive, and starting the placement cycle. The delivery arm's cycle time is the time for the arm to lower the marker onto the adhesive on the pavement, retract, and return to the delivery tray. Figure 9 is a view of the delivery arm during marker placement.

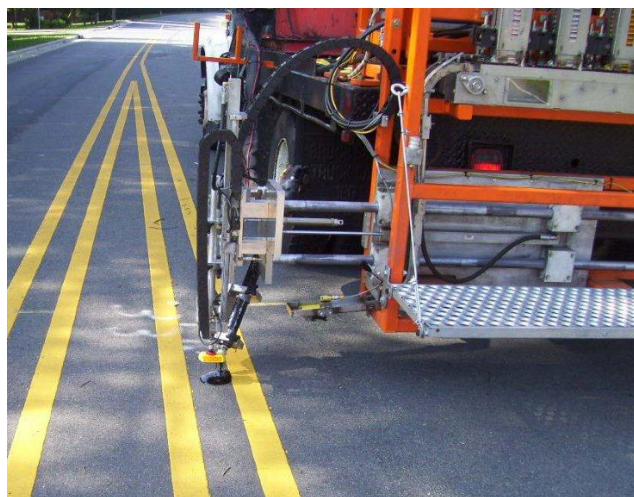


Figure 9. Marker placement.

Tuesday, May 10, 2011: Because of an issue with the bitumen adhesive system, no work was performed on this day.

Wednesday, May 11, 2011: The operator placed 801 markers in about 4.5 hours with only a few brief stops for troubleshooting. At the end of the first hour, 187 markers had been placed; by the end of the second hour, 374 had been placed. During these 2 hours, a marker was placed every 15 to 17 seconds. Later, during a stop, it was discovered that the cause for markers occasionally getting stuck at the top of the chute was a gap between the end of the conveyor belt and the top of the chute. The position of the chute was adjusted to close the gap. Also, the project team noticed during the day that the operator became so proficient positioning the truck that he had to wait a couple of seconds before the marker arrived at the delivery tray. Because a speed control was added as one of the modifications during Phase 2, the team was able to increase the speed of the conveyor belt so markers arrived at the delivery tray in less time. This resulted in a reduction in the placement time to 13 to 15 seconds.

Thursday, May 12, 2011: The operator placed 580 markers in about 5 hours. The operator needed to stop several more times to troubleshoot. The primary problems were 1) loss of vacuum pressure at the suction cup, 2) markers flying out of the delivery tray, and 3) markers getting stuck in the chute. The loss of suction was a result of the suction cup being lowered into the bitumen adhesive without a marker attached. The vacuum line was cleaned out and a section of tubing was replaced. Small cushions were added to the delivery tray to prevent markers from flying out of the tray, and more adjustments were made to the alignment of the chute.

Friday, May 13, 2011: The operator placed 696 markers in about 3 hours. This equates to a placement rate of 232 markers per hour. These results also indicate how quickly an operator can become proficient at operating the system. The previous best rate, which occurred on Wednesday, was 187 markers per hour. Friday's performance was a 24 percent increase in productivity.

Table 1 summarizes the productivity statistics recorded during the week. In the table, performance period is defined as the time spent placing markers, which includes time spent troubleshooting but excludes time for breaks and refilling the marker magazines and bitumen pot. Most frequent placement times were determined by counting the occurrences of all placement times (time to travel to the next marker plus time to place the marker) and selecting the range of placement times that occurred most frequently.

Table 1. Productivity statistics.

	Day 1	Day 2	Day 3	Day 4
Performance period (hours)	4	4.5	5	3
Number of markers placed	356	801	580	696
Production rate (markers per hour)	89	178	116	232
Most frequent placement time (seconds)	15–21	13–17	13–15	12–15
Number of markers placed within most frequent placement time	202	604	328	511

4. Comparisons to Traditional Placement Methods

As discussed in the Phase 1 report, one obvious benefit of this system over traditional manual methods is increased safety. In the traditional method, as shown in figures 10 and 11, a second person on the marker truck reaches out near live traffic to place the adhesive and the marker.



Figure 10. Traditional RPM placement method.



Figure 11. Closeup of traditional RPM placement.

The automated pavement marker placement system eliminates the need for this person and, therefore, the risk of the worker being struck by another vehicle on the roadway. The system also eliminates the occupational safety concern of workers being severely burned by the 500-degree Fahrenheit (260-degree Celsius) bitumen adhesive.

Visual inspection of the marker placements showed that the system can place markers as well as or better than the manual method. The system can adjust the bitumen flow rate to release the same volume of bitumen for each marker. Each time, the delivery arm centers the marker in the bitumen and places it with the same downward pressure, ensuring it is at the correct depth in the bitumen.

Another comparison between the automated system and the manual method is the potential for cost savings to pavement marker contractors. Cost savings can be experienced by redirecting labor or an increase in production rates. For contracts that require only the installation of new markers and no removal of old markers, the automated system may reduce one laborer from the marking crew. The total number of laborers needed depends on the number of crash/follow truck drivers required to provide traffic control, but this number is driven by the traffic volume and the automated system has no impact on this.

To compare traditional production rates to that of the automated system, the project team conducted a short telephone survey with four contractors that place raised pavement markers. All four contractors use a method similar to that shown in figures 10 and 11 in which a second laborer on the marker truck places the adhesive and the marker. The survey participants were asked what their typical production rates are. All four contractors stated that they have two different production rates depending on the type of roadway. Two-lane roads cause a decrease in productivity because of the delays for traffic maintenance. Installing markers on interstates or four-lane highways can be performed more quickly because of the extra traffic lanes. The production rate in a 12-hour work day on a two-lane road ranges

from 750 to 1,500 markers per day, and the production rate on a four (or more) -lane road ranges from 1,200 to 2,200 markers per day. The survey participants also reported having the capability to place between 400 and 700 markers before needing to stop to reload. Because the automated system's magazine rack holds 568 markers, the frequency for stops to reload should be similar to that of the traditional methods, but the time spent reloading the magazines may be a little longer.

To compare the automated system's production rate on a four-lane highway to that of the traditional method rates, the automated system's rate must be converted from hourly to daily. Assuming that in a 12-hour work day 2 hours are lost to travel time to and from the jobsite and another hour is lost to downtime for breaks and reloading, the automated system's hourly rate (232 markers per hour) should be multiplied by 9 hours. Therefore the automated system can place about 2,100 markers per day on a four-lane highway, which is at the high end of the rates for traditional methods.

5. Conclusion

In Phase 2 of this project, the project team made several modifications and upgrades to the automated pavement marker placement system. These changes increased the system's reliability and flexibility and made it easier to operate and maintain. In May 2011, the automated pavement marker placement system was used in its first full-scale application on an actual RPM installation contract. This allowed the project team to see how the system could perform in the real world under the conditions and environment of its intended use. A few minor modifications were made during the week of the installation, but by the end of the week the system was performing very well. The automated pavement marker placement system's advantages are 1) improved safety from eliminating the need for a laborer working near live traffic and with high-temperature bitumen, 2) consistent adhesive and marker placement, and 3) cost savings from one fewer laborer and potentially higher production rates.

Appendix: Phase 1 Progress Report

Phase 1 Progress Report: November 1, 2007–January 31, 2009

FHWA RFA No. DTFH61-08-G-00004
Highways for LIFE Technology Partnerships Program:
Automated Roadway Pavement Marker Placement System



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1. Summary

According to the Federal Highway Administration's (FHWA) plan, the grant project is divided into two phases: Phase 1—product redesign and building and Phase 2—field applications. Research and development activity of the grant project officially started on November 1, 2007. Phase 1 ended on January 31, 2009. This report summarizes the progress accomplished in Phase 1.

In the 15 months, the project team completely redesigned and rebuilt a new beta version of the proposed automated roadway pavement marker placement system. The new system went through rigorous workshop tests and was field tested to install raised pavement markers (RPMs) on roadways in North Carolina on November 12 and 13, 2008. An FHWA expert, North Carolina Department of Transportation (NCDOT) representatives, and other independent observers joined the project team to observe the actual installation operations of the system. An initial field testing report was submitted to FHWA in December 2008.

Based on comprehensive workshop and initial field testing results, the project team concluded that the system design is technically sound, the beta version of the system is built properly with its robustness, and the system is safe and reliable for actual applications in the real-world environment. The research team is ready to apply the system in actual RPM installation projects in Phase 2 of the grant project. This report contains: a) a summary of the major research and development activities in Phase 1, b) progress accomplished, c) marketability analysis, and d) work plan for Phase 2.

2. Summary of Major Activities in Phase 1

The detailed research and development activities performed in Phase 1 were described in the four quarterly reports ending December 2007, March 2008, June 2008, and September 2008; the annual progress report; and the initial field testing report. This section recaps the major activities.

2.1 Work Performed in November–December 2007

The major activity performed in the first 2 months of the project falls in the following six areas:

- Sign separate agreements between the grant recipient and its two subrecipients. After careful reviews, two subagreements were signed by the three parties. The parties showed their good will in the process, which created a collaborative culture for the team as it moved ahead with its planned research and development activities.
- Update the work plan and schedule for Phase 1 according to the new timeline approved by FHWA. Phase 1 was divided in two stages: Stage 1 (November 1, 2007, through August 31, 2008)—product redesign and building and Stage 2—initial testing and evaluation.
- Study Georgia’s RPM placement system. Funded by the Georgia Department of Transportation (GDOT), the Georgia Institute of Technology undertook a research and development initiative to develop a similar system. The project team carefully studied Georgia’s system. A teleconference was held with the participation of the two project teams.
- Conduct research on redesigning the four subsystems as outlined in the application. Research was conducted to study the following issues: control panel, power supply, wireless operator pendant, storage magazines, hydraulic cylinders, and glue pot.
- Brainstorm new ideas for improving the product and meeting the needs of the end user. The project team discussed new ideas and strategies that may further improve the product, such as productivity, system reliability, and essential needs of the end user.
- Support FHWA communication efforts. The project team provided the program manager with a draft article for trade magazines and materials for preparing posters for the Transportation Research Board (TRB) annual conference.

2.2 Work Performed January–March 2008

Between January 1 and March 31, 2008, the major activity focused on research on designing the four subsystems as outlined in the application.

- The delivery subsystem includes a robotic arm that takes a marker from the storage stack at the back of the truck, delivers it to the right location on one side of the truck, and places it on the roadway. In the original prototype, a vacuum-style suction cup was used to pick up the RPM. A mechanical arm then delivered the marker to position and held onto it until it was placed on the road. Field tests indicated system reliability problems associated with the vacuum systems, air cylinders, and pallet system. In the new design, hydraulic cylinders in the pallet transport the RPM out and down onto the road. A vacuum system powered with 12-volt electricity uses an air suction cup to hold the RPM and place it on the road. To compensate for the gravity from the downward motion of an RPM, the position where the RPM is temporarily held for the suction cup to pick up is installed with an energy dispersion pad so an RPM can land at the position properly regardless of its height. A sensor is installed in the robotic arm to inform the system when it has made contact with the road, indicating a successful installation of the RPM.

- Adhesive flows through a hose to the tip positioned near the roadway and discharges the adhesive on the ground. The hose must maintain an approximate 500-degree temperature internally to enable the material to flow freely. The equipment used in the original prototype needs to be modified to significantly reduce the heat loss in the hose at the joints and tip. The tip area where the adhesive comes out is made of a heat-resistant rubber that cannot hold the heat in. Heat loss is a big factor that slows down the placement of the RPMs because the operator must manually heat up the system with an external torch heat. The research team studied various strategies to alleviate the problem.
- The project team reviewed the control panel and identified what input and output will be needed.
- The platform subsystem provides the space to mount the hardware components. It can be attached to a construction vehicle when RPM placement is needed. The new design of this subsystem is integrated with stainless, aluminum, and heavy-gauge painted steel. Airbags are built into the system to relieve shocks when the truck hits bumps. The subsystem is portable with two major components that can be installed with a hilo to a mainframe. The mainframe is mounted to the truck.

2.3 Work Performed April–June 2008

Between April 1 and June 30, 2008, the major activity was redesigning the system and building some components. A three-dimensional (3D) design drawing of the entire system is shown in figure 1. Figures 2 and 3 show the front and back views of the system. Figure 4 shows the detailed design of the installation component.

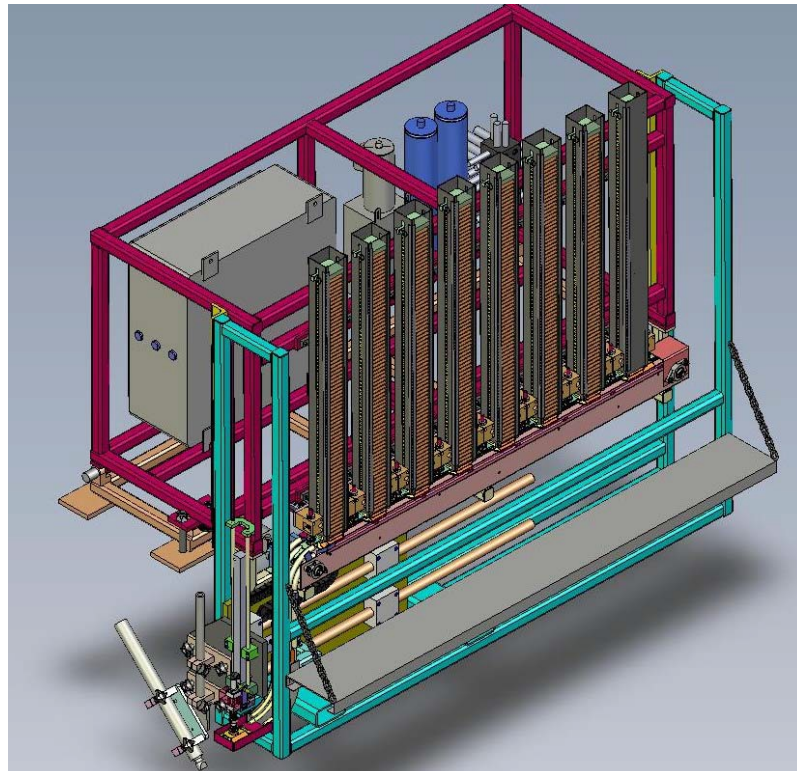


Figure 1. Entire system design (3D view).

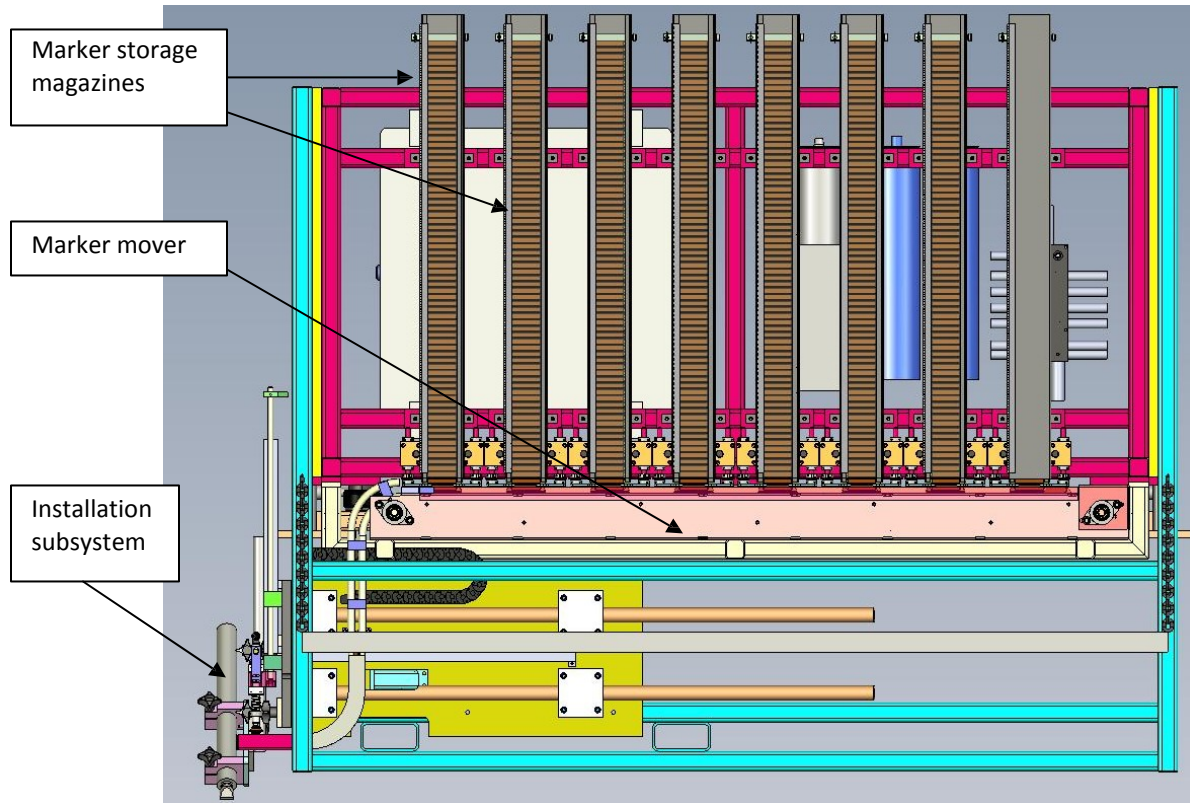


Figure 2. System design (front view).

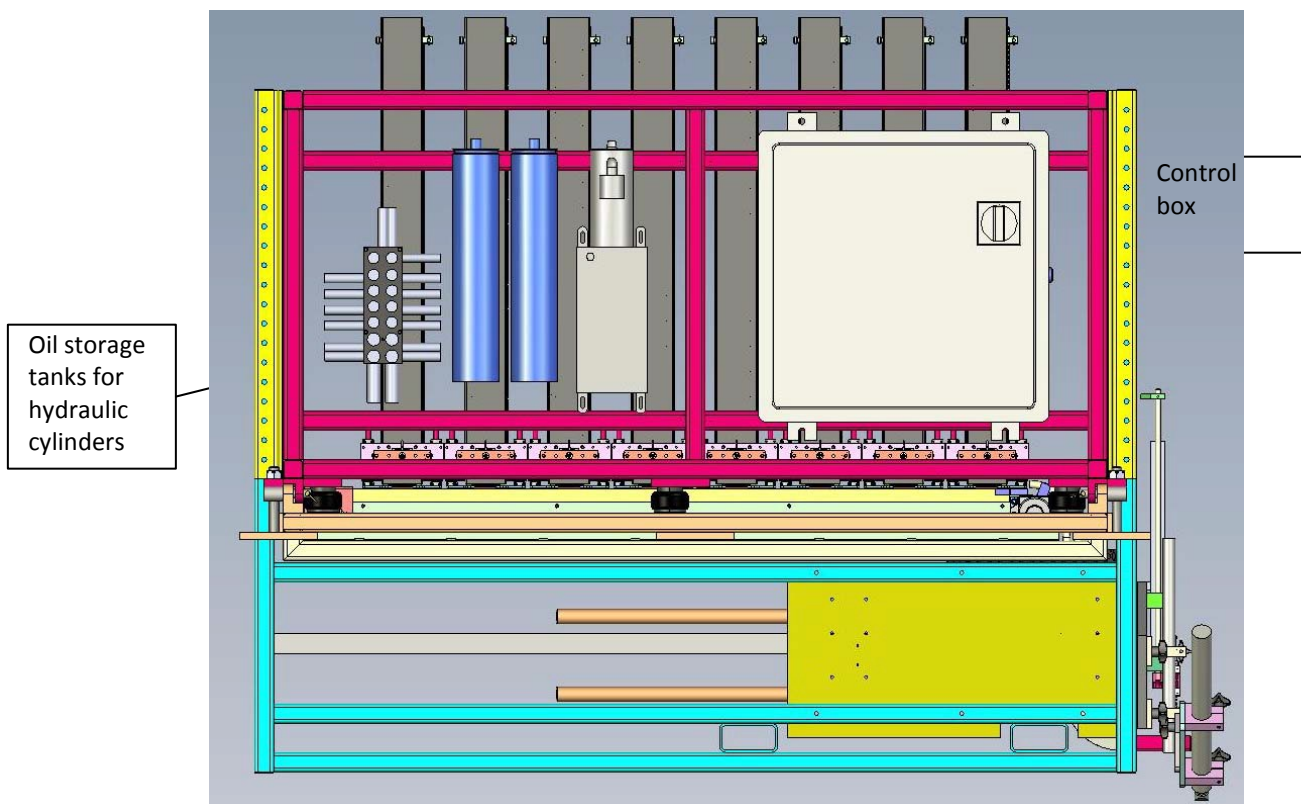


Figure 3. System design (back view).

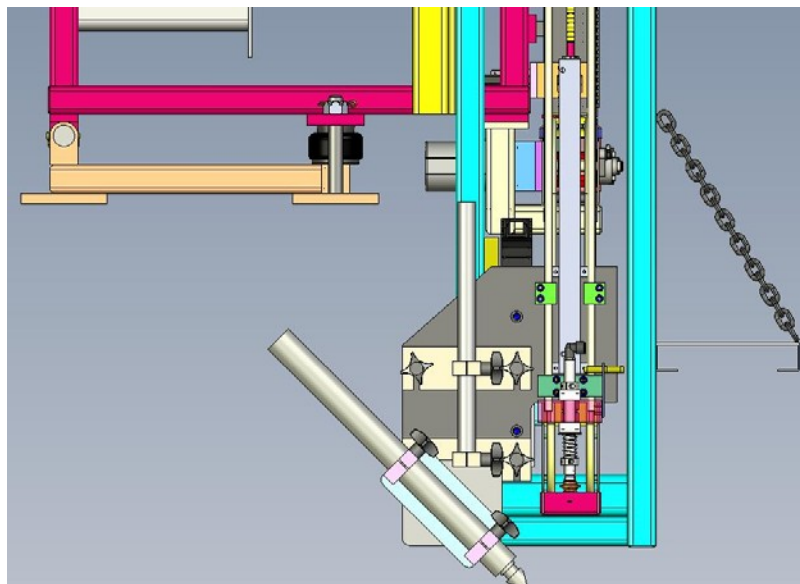


Figure 4. Installation component.

2.4 Work Performed July–September 2008

Between July 1 and September 30, 2008, the major activity focused on fine-tuning the system design and building individual components in the system. Figures 5 and 6 show front and back views of the system. Figure 7 shows the installation component.

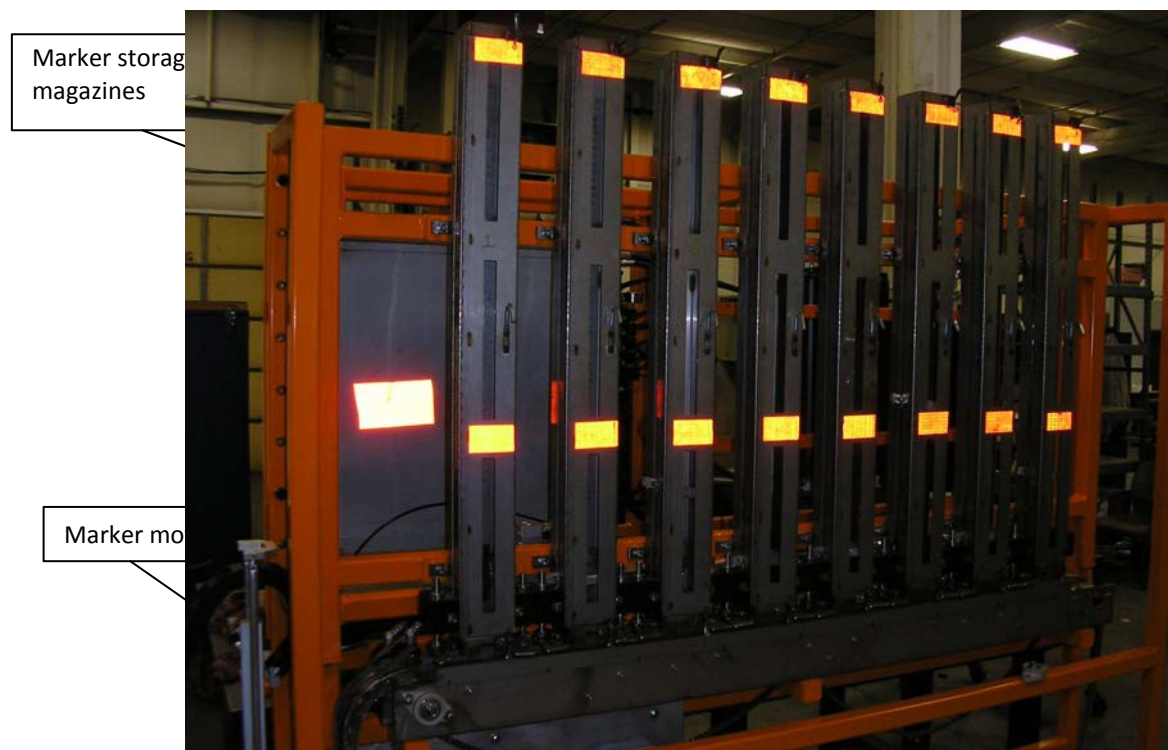


Figure 5. System front view.

Oil storage tanks for hydraulic cylinders



Control box

Figure 6. System back view.



Figure 7. Installation component.

2.5 Work Performed October–December 2008

The beta version of the RPM installation system was designed and built by Detail Technologies in Phase 1 of the grant project. The system was shipped to Stay Alert Safety Services, Inc. for planned initial field testing in November 2008.

Stay Alert organized a comprehensive field testing of the system November 12 and 13, followed by more testing of the system by its installation crew. Independent observers from FHWA, NCDOT, and 3M were invited to observe the operation of the system under actual working conditions. The entire team—including three key members of the engineering group from Detail Technologies, three key members of the application group from Stay Alert, and a consultant—was involved in the initial testing.

The initial field testing exceeded early expectations. The system design is technically sound. The beta version of the system is built properly with its robustness. Initial testing showed that the system is safe and reliable for actual applications in a real-world environment. The research team submitted an initial application report to FHWA in December 2008 with two independent assessment reports of the system from the 3M and NCDOT observers.

Initial field testing details are provided in Section 3.5.

2.6 Suppliers of Main Parts

The system was built with standard parts, where possible. The main parts installed in the machine and their manufacturers are as follows:

- Allen Bradley MicroLogix 1500 PLC
- Banner—photo eyes (puck present)
- Turck—proximity sensors for conveyor position
- E’Mation Controls—wireless pendant control
- Allen Bradley—solid-state control relay for conveyor
- Hoffman R3—enclosure for main controls
- Square D—disconnect for power control to main panel
- Square D—selector switches and push buttons, 22.5 millimeters
- Parker—hydraulic pump
- Parker—hydraulic motor that turns conveyer
- Michigan Fluid Power—hydraulic valve manifold
- Nason—all hydraulic cylinders

3. Progress in Phase 1 (Task 1.3 in Original Proposal)

As outlined in the original proposal, the automated RPM placement system consists of four subsystems: 1) the delivery subsystem for moving markers in the construction vehicle, 2) the adhesive subsystem for applying adhesive on the roadway, 3) the control subsystem, and 4) the platform for mounting the hardware components. The following sections describe the progress accomplished on these components.

3.1 Delivery Subsystem (Task 1.3.1 in Original Proposal)

The delivery subsystem includes a conveyor that moves a marker from a storage magazine to the landing area and a robotic arm that picks up the marker from the landing area at the back of the truck, delivers it to the right location, and places it on the roadway. As outlined in the

original proposal, three components in this subsystem have been successfully redesigned and rebuilt: a) the vacuum cup, b) the air cylinders, and c) the pallet system.

- **Vacuum cup:** The old prototype used an air compressor supply system that could cause moisture to transfer through the air lines. Once moisture got into the pneumatic valves, the valves tended to fail. The new vacuum system, shown in figure 8, was redesigned and rebuilt with a two-directional hydraulic system that can reliably pick up a marker and release the marker as needed. Comprehensive workshop and initial field testing showed that the new system has the needed high reliability.



Figure 8. Vacuum suction cup.

- **Delivery arm:** Air cylinders used in the old prototype showed shortcomings at the field tests when grit and grime got in the cylinder shafts because of rough outdoor road conditions. These cylinders were replaced with a robust hydraulic system in the new system, shown in figure 9. The delivery arm can stretch up to 2 feet (0.6 meter) to adjust its position for placing the marker. Comprehensive testing showed that the new system is reliable and efficient in delivering and placing markers.



Figure 9. Delivery arm can stretch 24 inches (0.6 meter) to adjust its installation position.

- **Pallet system:** A pallet system with eight storage magazines, shown in figure 10, was redesigned to hold up to 500 RPMS. All the magazines are installed on the frame. Two different types of markers can be stored in the magazines. The operator can choose either a yellow or white marker to be placed. After one magazine is empty or jammed, the next magazine is automatically activated.



Figure 10. Marker storage magazines.

Each magazine is installed with a dispenser that can push one marker out of the magazine at a time. As shown in figure 11, the dispenser is driven by a hydraulic cylinder. Compared to the old prototype, the new system is much more reliable. The plumbing of hydraulic lines to each cylinder is progressing. Each cylinder is plumbed separately to a manifold of valves. A sensor has been mounted on each magazine to identify if any markers are ready on demand.

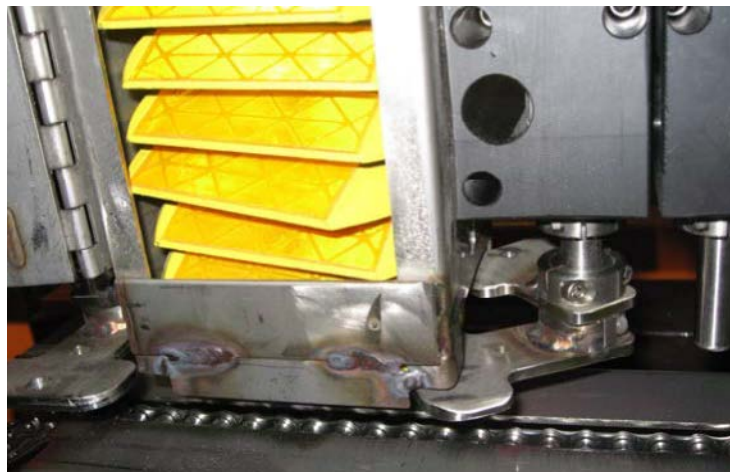


Figure 11. Marker storage magazine and dispenser.

In the old prototype, a marker fell on its gravity, causing problems during operations. For instance, a marker might jump out of the pallet when it came down from a far magazine with a long travel path, or a marker might stop in the pallet when it came from the nearest magazine with a short travel distance. The new design uses a dog to catch and move the marker horizontally to the left side. As shown in figure 12, the chain is installed with two dogs, one on the top and the other at the bottom (not visible in the figure), to continuously move the markers that are dispensed from their storage magazines. The chain is driven by a hydraulic cylinder. The hydraulic motor is mounted and plumbed. A sensor is mounted to the chain system to know the position of the dog. Tests showed that the new system has an extremely high reliability.



Figure 12. Marker mover.

3.2 Adhesive Subsystem (Task 1.3.2 in Original Proposal)

Adhesive flows through a hose to the tip positioned near the roadway and discharges the adhesive on the ground. The hose must maintain an approximate 500-degree temperature internally to enable the material to flow freely. Heat loss is a big factor that slows down the placement of the RPMs because the operator must manually heat up the system with external torch heat. The tip area where the adhesive comes out is made of a heat-resistant rubber that does not help hold the heat in. The adhesive system is provided by an independent manufacturer, Sherwin Industries, and the research team cannot make modifications to the system without the manufacturer's involvement. Instead, heating tapes are used to wrap up the entire hose and the cold spots to prevent heat loss, as shown in figure 13. Initial field testing showed that the measure helped improve the performance of the subsystem.

Meanwhile, the research team is working with the manufacturer to modify the system to significantly reduce the heat loss in the hose, at the joints, and at the tip. Sherwin Industries has shown interest in partnering with the research team in this area as the project moves forward. A representative from the manufacturer indicated it could relocate both the control panel and the junction box to fit the system design. He will also discuss with the manufacturer's engineers the possibility of removing the elbow connector at the end of the hose. It is expected that the adhesive subsystem will be modified to meet the system's need in Phase 2.

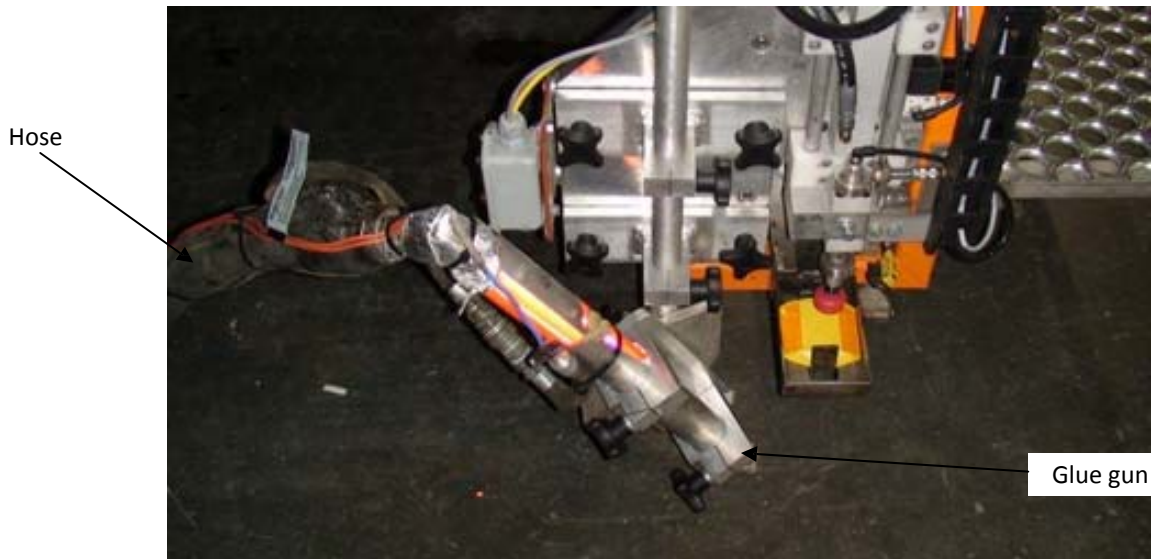


Figure 13. Adhesive system.

3.3 Control Subsystem (Task 1.3.3 in Original Proposal)

The control subsystem consists of two separate units that have been improved in the new system:

- The control panel is the brain of the entire system. It instructs each component on when to perform what; it also controls the sensors to determine the status of the components in the system. As shown in figure 14, the control subsystem is built in a box with all needed input and output ports. Extra ports are reserved for future enhancement. The control box is also installed with the control buttons to allow direct operation of the system in the back of the truck. This feature is desirable, especially at the testing stage. The initial field testing has shown that the subsystem is effective and provides an easy-to-use interface for the user to recode the control system with fault detection features as needed. For instance, when a marker was jammed on the first day of field testing, the installation arm could not pick up a marker, but continued its operation by pressing the suction cup on the hot adhesive. The control engineer quickly recoded the control system with a fault detection feature that can warn the operator of the problem and abandon the remaining operations.
- A wireless operator pendant is supplied in the new system to allow the driver-operator to operate the system inside the truck. The remote unit, shown in figure 15, can be powered from the cigarette lighter. The pendant has function buttons on it, such as power button, test adhesive, manual selector switches for each operation, automatic operation mode, and emergency shutdown. The unit can be enhanced with new features in Phase 2, such as adding a liquid crystal display screen to display text messages about the mode of the equipment and provide safety warnings.



Control Box

Figure 14. Control box.



Figure 15. Remote control device.

3.4 Platform (Task 1.3.4 in Original Proposal)

The platform subsystem provides the space to mount the hardware components. It can be attached to a construction vehicle when RPM placement is needed. As shown in figures 16 and 17, the new design of this subsystem is integrated with stainless, aluminum, and heavy-gauge painted steel. Compared to the old prototype, the new frame has the following major advantages:

- **Stronger and weather resistant.** Considering harsh working conditions on the road, proper materials were selected to make the frame much stronger and more resistant to weather.
- **Weight distribution.** The new design allows half of the frame to sit on the mounting truck so that a large portion of the weight of the system can be transferred directly to the base of the truck instead of completely hanging from the truck as in the old prototype. Airbags are built into the system to relieve shocks when the truck hits bumps.

Several adjustments are made to allow the frame to accommodate different types of trucks. The air cushion system was improved to handle more weight. Hilo tubes were installed for easily handling the unit during installation.



Figure 16. Frame structure.



Figure 17. Back view of frame.

3.5 Initial Testing and Applications (Tasks 1.4 and 1.5 in Original Proposal)

To insure the system's high performance, different types of tests were performed in Phase 1. A component-based approach was used to build the system. After each component was constructed according to design, a comprehensive workshop test was performed. Adjustments typically followed to ensure that the performance of the component met or exceeded the design expectation. After the entire system was assembled, it was again tested in the workshop and any needed refinements or adjustments were made. After the system's performance was determined stable and safe for field testing, the system was applied to install RPMs on the roadways in November 2008. This section summarizes these tests.

3.5.1 Tests Conducted in Detail Technologies Workshop

Depending on the complexity and testing results, each component was extensively tested after it was built until it reached the expected performance reliability. The following log shows the amount of time spent testing the major components:

- Cycle tested one de-gater and magazine system—5 hours
- Cycle tested one de-gater and magazine system—5 hours
- Cycle tested all eight de-gater and magazine systems, automated—20 hours
- Cycle tested all eight de-gater and magazine systems, automated—20 hours
- Cycle tested vacuum pickup system—15 hours
- Cycle tested conveyor, chute, and nest system—30 hours
- Cycle tested controller—10 hours
- Cycle tested entire system inside of detail—10 hours
- Cycle tested entire system inside of detail—10 hours
- Cycle tested entire system inside of detail—10 hours
- Cycle tested entire system on detail truck—10 hours

3.5.2 Initial Testing and Applications

The beta version of the RPM installation system was designed and built by Detail Technologies in Phase 1 of the project. The system was shipped to Stay Alert for planned initial field testing in November 2008.

The initial field tests were conducted by the construction crew at Stay Alert to serve the following purposes: 1) training the construction crew, 2) testing working conditions of the product, and 3) making small adjustments as needed for the equipment to meet the conditions for full-scale applications.

Stay Alert organized a comprehensive field testing of the system November 12 and 13, followed by more testing of the system by its installation crew. Independent observers from FHWA, NCDOT, and 3M were invited to observe the operation of the system under actual working conditions. The entire team—including three key members of the engineering group from Detail Technologies, three key members of the application group from Stay Alert, and a consultant—was involved in the initial testing.

a. Background

The purpose of the initial field testing was to fully evaluate the functionality of the refined product and its suitability for more field testing and actual applications by the contractor in Phase 2 of the project. In summer 2008, FHWA program manager Julia Zirlin, FHWA product expert Carl Andersen, and the project team decided to conduct initial field testing in November 2008. A field test was planned to apply the machine to install RPMs on actual roadways on November 12 and 13.

Andersen, NCDOT representatives, and other independent observers were invited to join the project team to observe the actual installation operation of the machine.

b. Observers Involved in 2-day initial testing

The individuals who observed or were involved in the initial testing are divided into two groups: the independent group and the research team. The independent group had the following observers:

- Carl Andersen—Roadway Team leader, Office of Research and Development, FHWA
- Chris Howard—Transportation Mobility and Safety Division, NCDOT
- Timothy J. Inglis—senior government transportation safety specialist, 3M

The project team that participated in the testing was as follows:

- Jim Babcock—general manager, Stay Alert, grant administrator
- Bryan Herrington—president and team leader, Detail Technologies
- Tony Collins—project manager and machine operator, Stay Alert
- Jonathan Shi—University of Nebraska-Lincoln professor and consultant
- Jeff Erhart—mechanic engineer, Detail Technologies
- Eric Edwards—control engineer, Detail Technologies
- Shane Strickland—installation team member, Stay Alert

c. Day 1 test on Wednesday, November 12, 2008

The field testing on Wednesday, November 12, was on Highway 158 starting at SR 1639 proceeding east in Davie County. The location was about an hour from Stay Alert's workshop, where the machine was assembled and tested. The machine was attached to the back of a normal RPM installation truck, as shown in figure 18.



Figure 18. RPM installation truck.

Before the machine was sent to the field, extensive testing was conducted in the workshop, as shown in figure 19, to test marker delivery, positioning, and installation operations. During the workshop testing, the adhesive subsystem was not used. The workshop testing provided a good opportunity to test the system's reliability and debug the system in an efficient and safe manner. The observers were satisfied with what they saw during the workshop testing.



Figure 19. Workshop testing on (a) positioning the marker and (b) picking up and placing the marker.

When the truck was traveling to the installation site, it could safely travel at the regulatory speed limits on all categories of roadways, including interstate highways. The new design allows half of the frame to sit on the mounting truck so that a large portion of the weight of the system can be transferred directly to the base of the truck instead of completely hanging from the truck as in the old prototype. Airbags built into the system can relieve shocks when the truck hits bumps. The driver did not find it difficult to drive the truck.



Figure 20. Installation operation under normal traffic conditions.

The field testing started at 11 a.m. and ended at 3 p.m. before the late afternoon rush hour. During the 4-hour period, a total of 300 (280 yellow and 20 white) markers were placed over a distance of 4 miles (6.4 kilometers). As shown in figure 20, the installation was conducted under normal traffic conditions. Stay Alert provided traffic control during the installation.

One person with a remote control operated the machine. It worked very well in the first hour, then suffered a brief setback that lasted about 40 minutes. After a long diagnosis, it was found that a loose coupling under the conveyor jammed the moving chain. After the problem was fixed, the installation resumed. In the remaining operation, the machine had a few more malfunctions, mostly caused by marks jammed in the conveyor system or in the storage magazines. The total downtime in the 4-hour operation was about 1 hour and 25 minutes.

Independent observers from NCDOT and 3M observed part of the operation. The research team watched the entire operation and debugged the system as needed. The operator expressed great satisfaction with the system. Figures 21 through 24 show the observed operations.



Figure 21. The cylinder can stretch 24 inches (0.6 meter) to adjust its installation position.



Figure 22. The marker was installed with the right amount of adhesive and force.



Figure 23. The installation quality could not be better, according to inspections.



Figure 24. The robotic arm can be retracted when a large truck passes by to improve safety.

In general, the testing on the first day was a great success. However, the research team also discovered some bugs, such as the following:

- The stop position of the carry dogs was sometimes too close to the last magazine on the right. When a marker was released from the magazine, it might fall right on top of the dog and jam the conveyor system, as shown in figure 25(a). The solution was to reposition the sensor to an earlier location.
- Some rough joints and cuts in the storage magazines caught markers by their sharp edges and caused magazines to be jammed several times, as shown in figure 25(b). The solution was to grind off the rough edges and joints of the storage magazines.
- Fault detection was not available. When a marker was jammed, the installation arm could not pick up a marker, but continued its operation by pressing the suction cup on the hot adhesive. The solution was to recode the control system with fault-detection features.

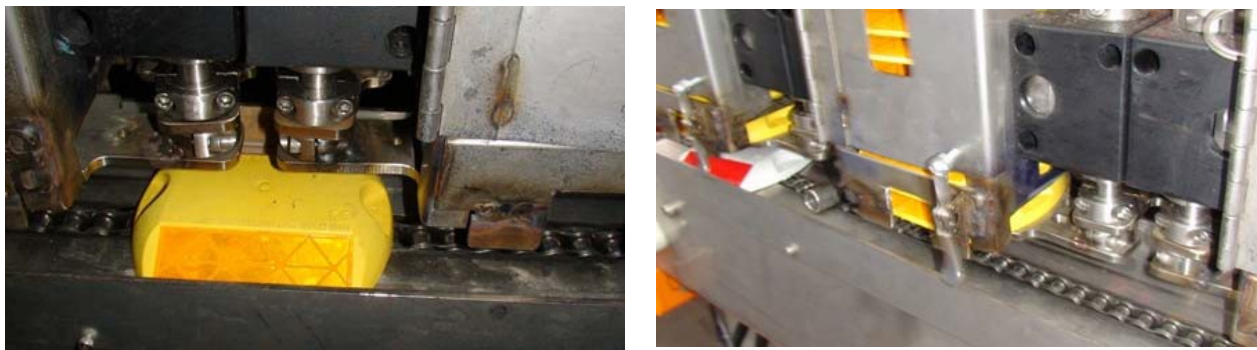


Figure 25. (a) A marker jammed the conveyor, and (b) a marker jammed the magazine.

In the evening, the research team went back to Stay Alert's workshop to implement the solutions. All problems discovered during the day were addressed properly. The machine was ready for another run.

d. Day 2 on Thursday, November 13, 2008

Although NCDOT issued a permit for the machine to be tested on a 10-mile (16-kilometer) stretch of Highway 150 on Thursday, November 13, 2008, rain prevented RPM installation on the highway as originally planned.

Instead, a brainstorming meeting was conducted in the morning for Andersen of FHWA and the project team to discuss their observations and suggestions for further improvements to the system. It was unanimously agreed that the field testing on the first day was a great success, the system design was technically sound, the system was simple and robust, and the testing did not show any major defects in the design and building of the system. The Detail Technologies engineering team agreed to examine the following technical issues to further enhance the product:

- Consider modular design of marker magazines to fit different types of markers. This is an optional feature. There is no immediate need to allocate resources to study this problem, but the project team realizes that this new feature will expand the machine to a broader market.
- Add a panel view to the control system to improve troubleshooting. This feature improves the user friendliness of the machine. The project team will design and build another remote control unit in Phase 2. Before the new control unit is built, the existing control can be used to operate the machine. The remote control shown in figure 15 is an independent component.
- Improve the heating system of the adhesive hose through the adhesive system instead of the marker controller. This problem cannot be resolved quickly. The project team will work with the adhesive supplier to address the problem in Phase 2.
- Consider training and preventive maintenance for users. The Stay Alert crew was trained during the initial testing. Training and preventive maintenance will be addressed in Phase 2.
- Update engineering drawings. During the building and field testing processes, the designs of many components were modified. The engineering drawings must be updated before a new unit is made. The technical team is working on it.

It was also agreed that the Stay Alert crew should conduct more extensive testing of the machine. After the meeting, the system was retested in the workshop while the adhesive subsystem was disabled. Both yellow and white markers were released from the eight magazines, as shown in figure 26. The testing lasted 2 hours and showed none of the problems encountered on the first day.

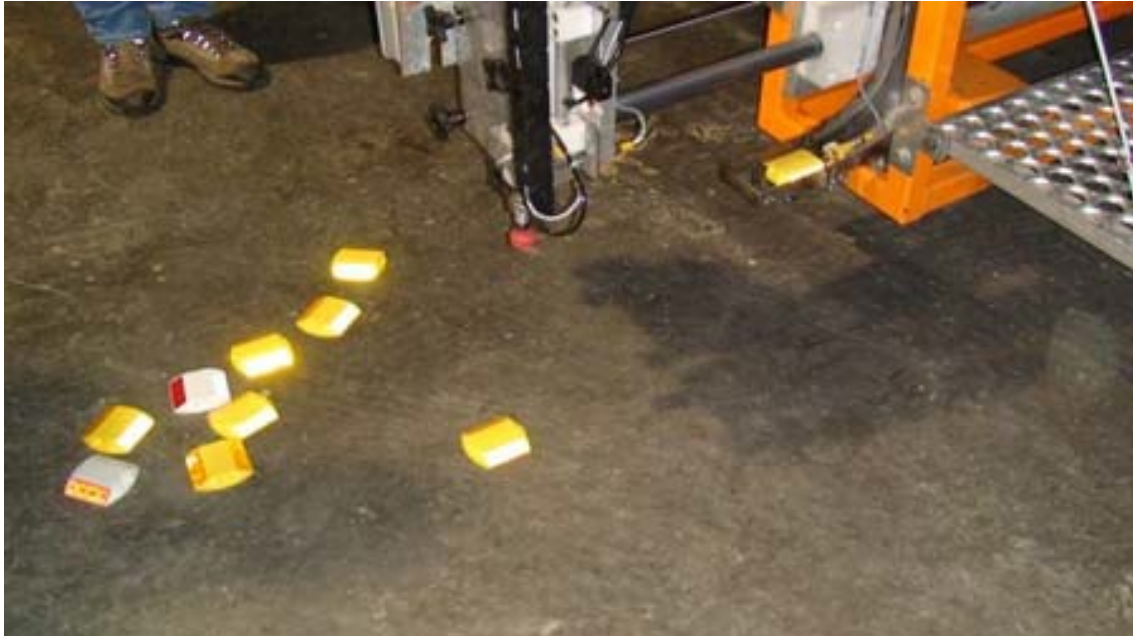


Figure 26. Workshop testing.

In the early afternoon, light rain continued. It was decided to test the machine under wet conditions, as shown in figure 27. For safety reasons, the testing was conducted on a private road with no traffic. The adhesive system was not activated. The main purpose was to test delivery and installation operations under wet conditions. The testing lasted about 2 hours with more than 200 markers successfully placed on the ground. No major problem was encountered. The testing demonstrated that the problems encountered on the first day were entirely resolved. The machine was much more robust.



Figure 27. Testing under light rain.

e. Additional testing

After the 2-day initial testing, the Stay Alert team performed additional testing of the system. First, it completed the remaining 2 miles (3.2 kilometers) on Highway 158. The markers all bonded extremely well on the 6-mile (9.6-kilometer) stretch, based on an inspection.

The machine was tested on another roadway from 10 a.m. to 4 p.m. on November 20, 2008. During the 6-hour operation, 427 markers were installed. A total of 12 system faults occurred, which were caused by markers jammed at the landing area. This kind of problem can be easily and quickly fixed by the crew by removing the jammed marker and resetting the system. Most of the problems stemmed from inconsistency in the quality of markers, some of which had a distinctive edge that slowed them down when they came down the chute and could stop them before they reached the landing area. As shown in figure 28, the chute is like a slide. Some refinements can be made to enable markers to slide down consistently.



Figure 28. Marker shooter in raw form.

f. Summary of initial testing

In conclusion, the initial field testing exceeded early expectations. The system design is technically sound. The beta version of the system is built properly with its robustness. The initial testing showed that the system is safe and reliable in applications in the real-world environment. Although small adjustments can be continuously made to improve the machine's performance and reliability, it is generally agreed that no major redesign or revisions are immediately needed before Phase 2. Andersen of FHWA will submit his evaluation report separately. Two independent observers from 3M and NCDOT provided their assessment of the system, attached to this report in the appendix.

4. Commercialization Analysis

As one of the drivers for this innovation, safety is the biggest benefit, and it has been demonstrated in the initial applications. In Phase 1, the project team focused its effort on the system design and its technological feasibility. The limited field testing has demonstrated that the machine is safe for full-scale applications. Full-scale field applications are essential to provide detailed system performance information for use in conducting a marketability analysis. As expected, a more detailed marketability analysis will be available in the Phase 2 report. The rest of the section presents different perspectives of the machine.

4.1 Proved Benefits

The initial field testing has demonstrated the following benefits of the innovation:

- **Safety.** The machine eliminates the need for a worker to face a high risk of being struck by vehicles on the roadway and an occupational safety concern of being exposed to a dangerous substance at a high temperature in a manual installation operation, as shown in figure 18.
- **Labor savings.** One person can operate the truck and the machine safely and smoothly. Therefore, using the machine can eliminate the need for an additional worker to place markers.
- **Quality.** The RPMs installed using the machine bound on the roadway very well. Visual inspection and testing proved that the RPM installation was of a high quality.

4.2 Construction Productivity

In the initial applications, the machine could not beat the production of a human crew. Several factors contributed to the outcome, including the skill of the operator and system bugs. The operator did a good job in the initial applications. The project team observed a continuous improvement of efficiency in the initial application as the operator became more familiar with the machine. Training may further improve efficiency. During installation, various bugs and other issues shut the process down from time to time. Many bugs were fixed during the 2-day field testing. The improvement in efficiency in the third-day application was very significant (with 427 RPMs installed in 6 hours). As the identified refinements are completed in Phase 2, the machine's efficiency can be further improved. The machine is designed with a 6-second cycle time. Assuming 9 seconds for the truck to get to position, one marker can be installed in 15 seconds, which translates to 240 markers per hour. This production rate is higher than a human crew. Therefore, it is possible that the machine can place as many or more markers as a worker can. In Phase 2, two full-scale applications will provide more detailed information on the machine's productivity.

4.3 Marketability

It is difficult to estimate the manufacturing cost of the machine at this time because only one was made and much research was involved in manufacturing it. A ballpark estimate to manufacture one unit is around \$75,000. If five units are made at a time, 10 percent savings are expected. The price may come down further after more research in Phase 2. Detail Technologies has the production capacity to manufacture one or multiple units as needed.

The project team cannot determine for certain whether the market can accept the innovation at the above price. The team has observed different perspectives from its communications and interactions with many highway professionals. From a safety perspective, the innovation is well received. If the machine's efficiency can be further improved, it will become more attractive for contractors, who are typically paid by number of markers installed.

In Phase 2, the project team will gather more relevant information from field applications so the picture can become clearer.

5. Work Plan in Phase 2

The research team successfully completed all research and development tasks in Phase 1 of the grant project and fully accomplished its Phase 1 objective. In Phase 2, the objective is to test the system in the real-world environment, to further refine the product as needed, and to evaluate the true benefits of the system in terms of improvements in safety, mobility, and construction productivity. Phase 2 is expected to last 9 months, from February 1 to October 31, 2009. The following sections describe the Phase 2 work plan corresponding to the work plan outlined in the original proposal.

5.1 Field Tests (Task 2.1 in Original Proposal)

This task was moved to Phase 1 as Task 1.5 as requested by FHWA.

5.2 Actual Applications (Task 2.2 in Original Proposal)

This task will apply the system on two actual RPM placement projects. To objectively evaluate the product, different types of projects will be selected. It is expected that one project will be selected from Stay Alert's project pool, and the other one will be performed in collaboration with a partnering contractor (Give 'Em A Brake Safety Inc. or Clark Pavement Marking Inc., depending on their project pools). NCDOT engineers will be invited to observe the production.

In the applications, the project team will send one member to be on the site all the time to record detailed engineering and performance parameters of the system. The firsthand data will provide the basis for Task 2.3—product evaluation.

In North Carolina, RPM projects typically start in March. Accordingly, this task will begin in March 2009 and last 4 months. The deliverables include detailed field engineering and performance data including, but not limited to, safety, equipment reliability, production, cost, and comments from the crew.

5.3 Product Evaluation (Task 2.3 in Original Proposal)

This task will include comprehensive and objective product evaluation based on the data collected from actual applications by employing various scientific methods such as statistical analysis, comparative studies, data mining, and trend analysis. The benefits of the product will be analyzed in the following criteria: 1) improvement on safety, 2) impact on work zone mobility, 3) reduction of construction time, 4) improvement of construction productivity, 5) reduction of labor cost per hour, and 6) overall cost savings.

This task is expected to last 2 months with a detailed evaluation report as its deliverable.

5.4 Further Refinements as Needed (Task 2.4 in Original Proposal)

The initial field testing has shown that no major redesign or modifications are immediately needed before Phase 2. Nevertheless, the project team has discovered that some technical improvements may further enhance the machine:

- The magazine system could be redesigned to be a bolt-on system, so if other types of RPMs were used the magazine could be swapped out.
- Consider modular design of marker magazines to fit different types of markers. This is an optional feature. There is no immediate need to allocate resources to study this problem, but the project team realizes that this new feature will expand the machine to a broader market.
- Add a panel view to the control system to improve troubleshooting. This feature improves the user friendliness of the machine. The project team will design and build a

panel view in the existing control panel. Meanwhile, it will explore the possibility of adding a panel view in the remote control unit.

- Improve the heating system of the adhesive hose through the adhesive system instead of the marker controller. The additional heaters that were attached to the hose to add heat to the cold spots are wired to the RPM power supply as a temporary solution. The power needs must be shifted to the glue pot power supply. This problem cannot be resolved quickly. The project team will work with the adhesive supplier to address the problem in Phase 2.
- The de-gater system below the magazines needs improvement to assure that the paddles will not turn out of the proper alignment if there is a failure with the magazine (e.g., a jam). As shown in figure 11, this adjustment may not be done quickly.
- Redesign the conveyer with reverse motion. As shown in figure 25(b), if there is a jam and the conveyer is involved, the quickest way to fix this jam is to reverse the conveyer. Currently the conveyer cannot reverse. A valve can be installed to allow the operator to manually switch it. The valve would reverse the hydraulic flow and move the conveyer backward as needed.
- Redesign the chute and landing area. Because of inconsistencies in RPM quality, a redesign of the chute and the landing area, as shown in figure 28, will ensure that all markers can slide down and land at the right location successfully.
- The two main pieces of the machine are assembled together with bolts that thread into the mainframe. It is easier if the holes for these parts have clearance holes and a bolt-and-nut system is used instead. This can be conveniently modified.
- The hydraulic motor of the conveyer needs a redesigned coupler that will not create alignment issues.
- Consider training and preventive maintenance for users. The Stay Alert crew was trained during the initial testing. Training and preventive maintenance will be addressed in Phase 2.
- Update engineering drawings. During the building and field testing processes, the designs of many components were modified from the original design that will need to be reversed engineered to put the modifications back to the design. The engineering drawings must be updated before a new unit is made.

This task will be performed on a continuous basis and in parallel with other tasks. The technical team is working on some small items. It will carefully study the above improvements and closely monitor the full-scale applications in Phase 2 to determine priorities for improving these features.

6. Conclusion

The project team successfully completed all research and development tasks and fully accomplished its objectives in Phase 1 of the grant project as planned. It completely redesigned and rebuilt a new beta version of the proposed automated roadway pavement marker placement system. The new system was tested in the workshop and in the field to install RPMs on actual roadways. The testing results showed that the system design is technically sound, the beta version of the system is properly built with its robustness, and the system is safe and reliable for actual applications in the real-world environment. The team looks forward to continuing its work in Phase 2.

Appendix: Observations from Independent Observers

Comments from Timothy J. Inglis of 3M

Comments from Chris Howard of North Carolina Department of Transportation

3M Atlanta Sales Center

105 Crafton Park Lane
Cary, North Carolina 27519
919-225-3122
919-362-3831 (Fax)



November 19, 2008

Mr. Jim Babcock
Stay Alert Safety Inc.
272 Clayton Forest Road
Kernersville, NC 27284

Dear Jim,

Thank you for your consideration in allowing us to participate in the testing of the Automated Raised Pavement Marker Machine that is under the FHWA Highways for LIFE grant program.

On Wednesday November 12, 2008, I had the opportunity to view and video the automatic installations of RPM on NC 158 in Davie County. Even though NC 158 is a curvy two-lane road with higher than normal traffic, the automatic raised marker applicator did a great job of installing markers while providing safety to the workers and minimizing inconvenience to the motorist. From a technical perspective, I was particularly interested in how the 3M markers were being placed in the adhesive. An RPM placed in the adhesive too deep or not deep enough can deem the marker non-functional. The automated truck placed the markers in the adhesive from what seemed to be the 'right' amount of pressure and with consistency that is difficult to replicate with human application.

Interstate RPM applications are very dangerous and un-nerving for the installer applying them the traditional way. It would be interesting to see (video) a comparison between the automatic marker truck and traditional application. The safety benefits and efficiency rates on a high volume interstate would be very telling.

I would once again like to thank you for this opportunity to view this innovative application. We at 3M take great pride in safety and support any efforts to increase it. Please do not hesitate to contact me with any questions.

Best Regards to you,

Timothy J. Inglis
Senior Government Transportation Safety Specialist
3M – TSSD

From: Howard, Chris B [mailto:cbhoward@ncdot.gov]
Sent: 2008-11-17 11:45
To: Jim Babcock
Cc: Schleich, John E.; Beard, Derrick H.; King, Ronald; Couch, John P.
Subject: Automated raised pavement marker machine

Jim,

Thanks for inviting John Schleich/Standards Engineer, Derrick Beard/Standards Engineer and myself/Standards Project Design Engineer to observe the automated raised pavement marker machine on 11/12/08. I believe this is a great concept and wanted to briefly describe my observation regarding the traffic control and machine itself.

I understand we are all looking for increased productivity, but more importantly we cannot sacrifice safety. It seems this machine could improve the safety factor when applying raised markers. I believe an alternate traffic control for this operation on two-lane, two-way roadways with severe horizontal and vertical curves would be flaggers using a pilot car. This would alleviate the "starting and stopping" to allow traffic to pass safely on these roadways. The moving operation you used that day would be fine for multilane roadways. What really stood out was the elimination of a person physically installing the markers. Any time we can eliminate people working in the center of the roadway is a plus.

The machine seemed to work really well for its first run. I did see a little dripping of the bitumen adhesive, but was no more than what I've seen in the past applying markers the traditional way. Getting the correct setting or location of the markers in the center of the double yellow seemed to be a little tedious. Maybe you could use something similar to the pavement marker contractors, which is an arm in the front of the application truck that extends out (like a school bus) that the driver could use to stay in the center of the double yellow without having to look in the rear view mirror.

Once again, I think the real bonus of this machine is getting the individuals out of the center of the roadway. I was very impressed with its first real run and believe production will improve over time.

Thanks again,

Chris

Signing & Delineation Unit
NCDOT-Transportation Mobility and Safety Division
Office: (919) 773-2909