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16. ABSTRACT Lane closure operations expose workers to physically demanding work and to traffic hazards. The AutoCone trailer was evaluated as a potential solution to reduce worker exposure and improve safety. The design has value for use by crews that place long closures regularly. It is recommended that the design be incorporated onto a truck and modified for use with the standard Caltrans 28-inch cone.		
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# **Advanced Highway Maintenance and Construction Technology Research Center**

Department of Mechanical and Aerospace Engineering  
University of California at Davis

## **Evaluation of the AutoCone 130**

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Ty Lasky: Principal Investigator

Report Number: CA21-3273  
AHMCT Research Report: UCD-ARR-21-03-31-02  
Final Report of Contract: 65A0560 and 65A0749 Task 3273

March 30, 2021

## **California Department of Transportation**

Division of Research, Innovation and System Information

# Executive Summary

Lane closure operations expose workers to physically demanding work and to traffic hazards. The AutoCone 130 trailer was evaluated as a potential solution to reduce worker exposure and improve safety.

## Problem

The California Department of Transportation (Caltrans) sets up highway lane closures daily throughout California to create work zones for workers to conduct highway maintenance activities. In high-traffic areas, lane closures are a high-risk operation. Presently, a standard cone truck requires a minimum crew of two, one to drive the truck and the other to drop off or pick up the cones. The crew operating the cones must manipulate the cones by hand, which can be physically demanding and may expose the crew to traffic.

## Background

The safety of workers and the users of California's transportation system is Caltrans' number one priority. Caltrans is constantly working to improve the safety for all Caltrans workers and the public. The AutoCone 130 will potentially lower the risk of traffic exposure by reducing the number of operators to one and by keeping the operator in the safety of the vehicle's cab. The AutoCone 130 is not in production but may be copied for use by Caltrans. The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center developed and licensed an automated cone machine in the late 1990s as part of Caltrans' efforts to improve safety. AHMCT was tasked to evaluate the AutoCone 130 developed by Centreville Manufacturing in Centreville, Maryland.

## Overview of the Work and Methodology

AHMCT, in coordination with Caltrans, obtained two AutoCone 130 trailers. The AutoCone 130 cone trailer was tested and evaluated to determine if it works as advertised, document the decrease in worker exposure to traffic, compile other benefits and drawbacks, and obtain feedback from Caltrans staff after they used the machine. This research evaluated the performance of and provided recommendations for the AutoCone 130, including the possibility of Caltrans Division of Equipment (DOE) mounting it onto a truck.

# Major Results and Recommendations

The major results and recommendations are as follows:

- The AutoCone 130 trailer cannot be used in Caltrans operations since it cannot retrieve cones while backing up. A truck-mounted system is required. It also must be redesigned to use the Caltrans 28-inch cone.
- An AutoCone 130 carries 130 cones. It is not likely to be a substitute for the typical Caltrans cone body truck due to the large size and cost. The typical maintenance lane closure requires 80 cones.
- A truck-mounted redesigned AutoCone 130 would be useful in locations such as the Bay Bridge where Caltrans places a 5-mile closure on a regular basis. Increasing the capacity to at least 260 cones is recommended.

Future work is suggested as follows:

- Modify the existing AutoCone 130 trailers to increase reliability and test with maintenance crews.
- Review the design details with DOE to assess the feasibility of mounting the AutoCone onto a truck frame.
- Consider the latest commercially available automated cone machines.

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# List of Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
Caltrans	California Department of Transportation
DOT	Department of Transportation
DRISI	Division of Research, Innovation and System Information
DOE	Division of Equipment
GVWR	Gross Vehicle Weight Rating

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# Chapter 1:

## Introduction

### Problem

The California Department of Transportation (Caltrans) sets up highway lane closures daily throughout California to create work zones for workers to conduct highway maintenance activities. In high traffic areas, setting lane closures is a high-risk operation. Presently, a cone truck requires a minimum crew of two, one to drive the truck and the other to drop off or pick up the cones. The crew operating the cones must manipulate the cones by hand, which can be physically demanding and may expose the crew to the traffic.

### Objectives

The safety of workers and the users of California's transportation system is Caltrans' number one priority. Caltrans is constantly working to improve the safety for all Caltrans workers and the public. Using an AutoCone 130 will potentially lower the risk of traffic exposure by reducing the number of operators to one and by putting the operator into the safety of the vehicle's cab.

If the AutoCone 130 performs as advertised by the manufacturer, this device will potentially reduce the labor for lane closures and improve the safety of the maintenance workers conducting lane closures. The objective of this research task was to evaluate the accuracy of manufacturer claims and determine the machine's overall value to Caltrans operations.

### Background

The AutoCone 130 will potentially lower workers' risk of traffic exposure by reducing the number of operators to one and by putting the operator into the safety of the vehicle's cab. The AutoCone 130 is not in production but may be copied for use by Caltrans. The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center developed and licensed an automated cone machine in the late 1990s as part of Caltrans' efforts to improve safety. AHMCT was tasked to evaluate the AutoCone 130 developed by Centreville Manufacturing in Centreville, Maryland.

### Literature

No formal literature search was performed as part of this project. Internet searches were performed during the project and identified additional machines that may be available in the near future.

# Research Methodology

AHMCT procured two existing AutoCone 130 trailers along with spare parts and associated documentation. Caltrans Division of Equipment (DOE) developed specifications and performed the inspections at the vendor's facilities and upon receiving the machines in Sacramento.

AHMCT developed a list of test objectives and tested the AutoCone trailers to assess the research questions listed in Chapter 4. AHMCT, with assistance from Caltrans and based on prior cone machine development, documented details of the standard cone laying process to establish the basis for testing and comparison.

The following deliverables were defined:

- The summary of the AutoCone 130 test plan and results is documented in Chapter 3.
- AutoCone 130 testing was executed to address the research questions. Testing at different temperatures and speeds was a primary goal.
- Due to limited field testing with Caltrans personnel, the effort to obtain user feedback on likes/dislikes, maintenance issues, operational issues, and requests for improvements was limited to meeting discussions. The machine was unreliable and testing with Caltrans will be performed after incorporating some design changes. Assessment of whether workers accept the machine and want to use it is not yet adequately known.
- Caltrans clearly indicated the preference to mount the AutoCone on a truck.
- The AutoCone 130 testing is documented in Chapter 3.
- The AutoCone 130 evaluation was developed based on test results and in conjunction with the Caltrans technical advisory group.
- The AutoCone 130 evaluation is documented in this Final Report.

# Chapter 2:

## Description of the AutoCone 130

The AutoCone machine and its operation are described in this chapter. Some design and operational issues experienced during testing are noted. A copy of the manufacture's specification sheet is provided in Appendix A.

### Two Machines

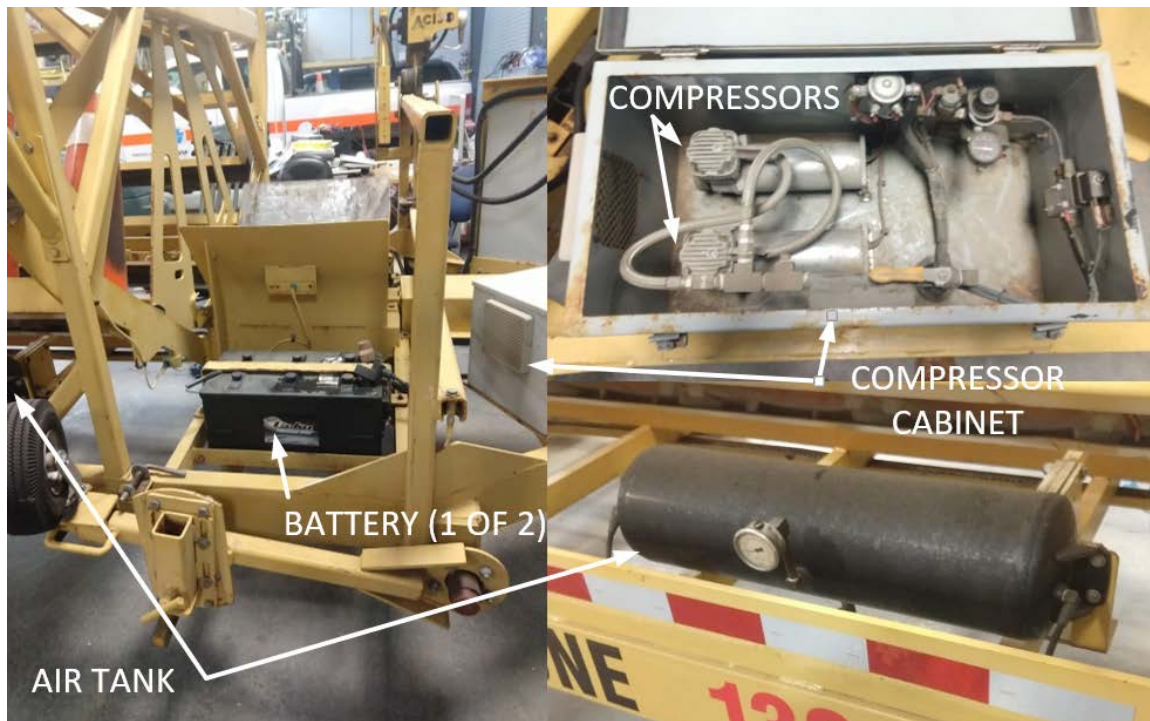
Two machines, shown in Figure 2.1, were purchased and delivered to Caltrans in September 2019. These trailer-based machines were built in 2007 and 2008 and are identical except that one includes the option for automating the spacing between cones. The trailers have a gross vehicle weight rating (GVWR) of 10,000 lb. The trailer weighs 4,742 lb when empty and carries 130 weighted 36-inch cones. The load of 130 cones weighs about 2,200 lb. The trailers measure approximately 27 ft in length. The drum holding the cones measures 8 ft in diameter and 16 ft in length.



Figure 2.1: Two AutoCone 130 machines at Caltrans

### Power and Controls

The system is powered by two Group D 12-volt batteries. The batteries are located on the trailer tongue as shown in Figure 2.2. The batteries are wired in series to produce 24 volts, which powers six geared electric motor actuators, the control system, and lighting accessories. A battery-powered pneumatic system powers one additional actuator.



**Figure 2.2: Battery and air compressor components**

A programmable logic controller is used to control the system. It is built into the control panel shown in Figure 2.3. The operator uses switches on the control panel door to set basic operating parameters. Proximity switches and photoelectric switches provide inputs to control the machine.

The two trailer control pendants are shown in Figure 2.4. The larger pendant is used to control the machine with the automated cone spacing option. During operation, the pendant is located in the truck cab with the operator. It is connected to the control panel with a 30-ft cable that passes out of the cab through a window back to the control panel on the front of the trailer



Figure 2.3: Control panel



Figure 2.4: Control pendants

# Mechanical Components

The various AutoCone components are described below. Terms used to describe the machine are based on the vendor's terminology.

## *Drum and Drum Lock*

The drum is the defining feature of the automated machine. It holds the cones by the base in 10 rows of 13 cones. A view from the rear is shown in Figure 2.5. The cones are held in slots referred to as the drum tracks. The drum track sliding surface is coated with a dry lubricant to reduce the sliding friction of the cones in the tracks.

Drum indexing is commanded by the operator at the pendant. This is done after a track is emptied when placing cones or after a track is filled when retrieving cones. The drum rotates clockwise in the view shown. The operator controls the drum indexing sequence to minimize unbalanced conditions.

The drum is actuated by an electric motor and gear box shown in Figure 2.5 and is held in position by the drum lock. The drum lock is chain driven and powered by a geared motor as seen in Figure 2.5.

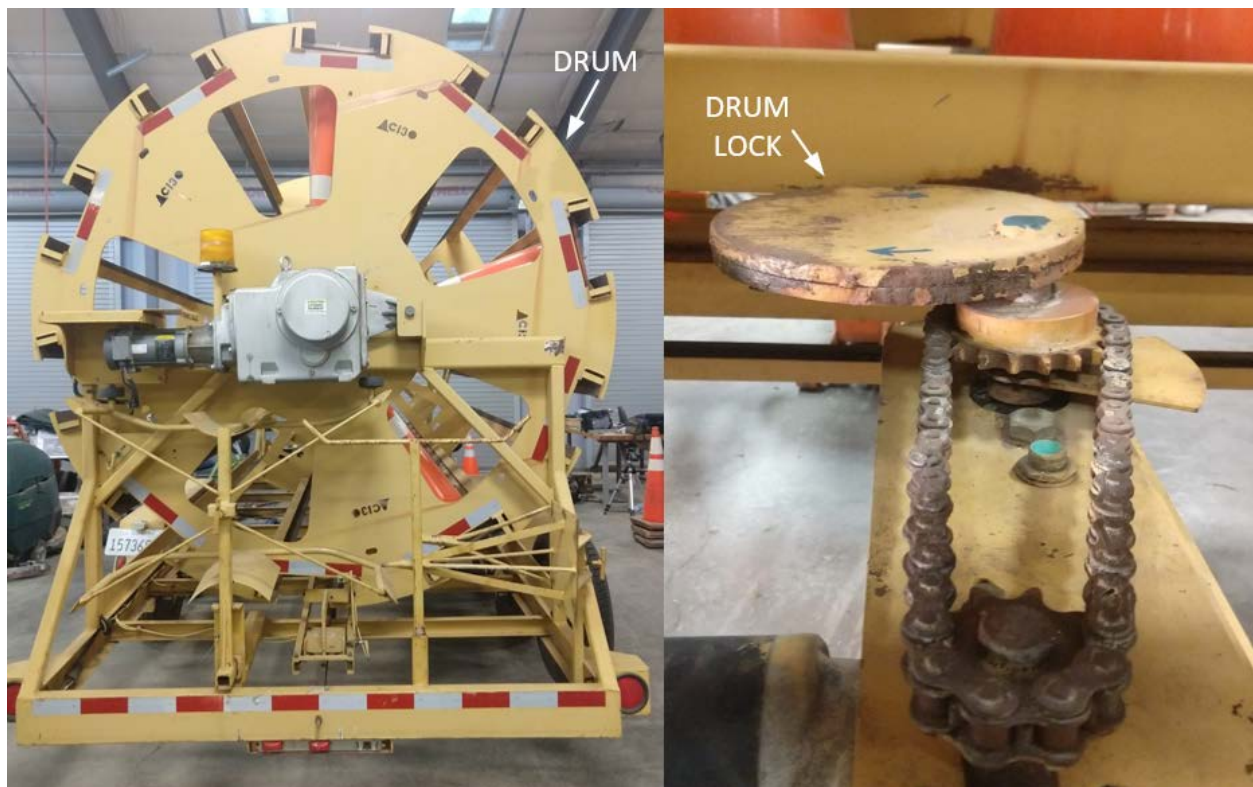


Figure 2.5: Drum and drum lock

## Chute, Shuttle and Pusher

The chute, shuttle, and pusher are shown in Figure 2.6. The chute is the location at which a cone is either picked up to deploy on the road or pushed into the drum.

The shuttle is shown in its rearward position while the drum slot is being indexed. It pushes the stack of cones forward as the cones are being placed by the machine. The shuttle is actuated by a chain drive that runs the length of the drum. The chain drive motor is located at the forward end of the AutoCone. Before the drum can be indexed, the shuttle returns to the rear of the machine. The shuttle is operated only while placing cones.

The pusher pushes each cone from the chute into the drum while cones are being picked up.

Both the shuttle and the pusher move the full row of up to 13 cones.

Problems with the pusher were limited to a single event. The pusher jammed in the position seen in Figure 2.6. A hard braking event caused cones to shift forward in their tracks. Drum indexing caused a cone to snag on a metal guide at the rear end of the chute. This folded into the path of the pusher, causing it to jam. This can be resolved with minor design changes.

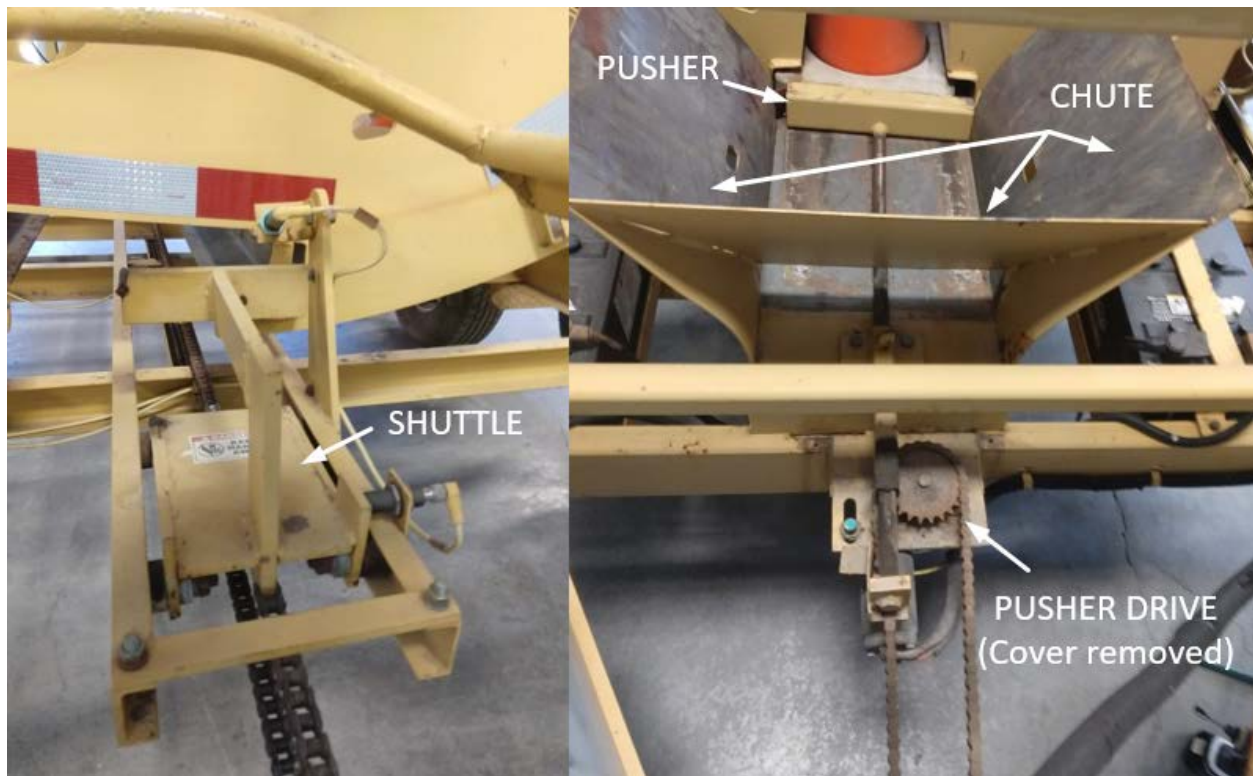


Figure 2.6: Chute, shuttle and pusher

## Arm and Claw

The arm and claw are shown in Figure 2.7. The arm rotates to move a cone from the chute to the road when placing cones. It moves a cone from the retrieving mechanism, described below, to the chute when retrieving cones. It is driven by a variable-speed electric motor, and the control system uses an 8-bit encoder to track the arm position.

The claw at the end of the arm grabs the tip of the cone. It is actuated with a pneumatic cylinder. The arm and claw are linked with a chain that causes the claw assembly to maintain a vertical orientation as the arm rotates. This keeps the cone in a vertical orientation. Swinging of the cone is minimized as it is moved along the circular arc.

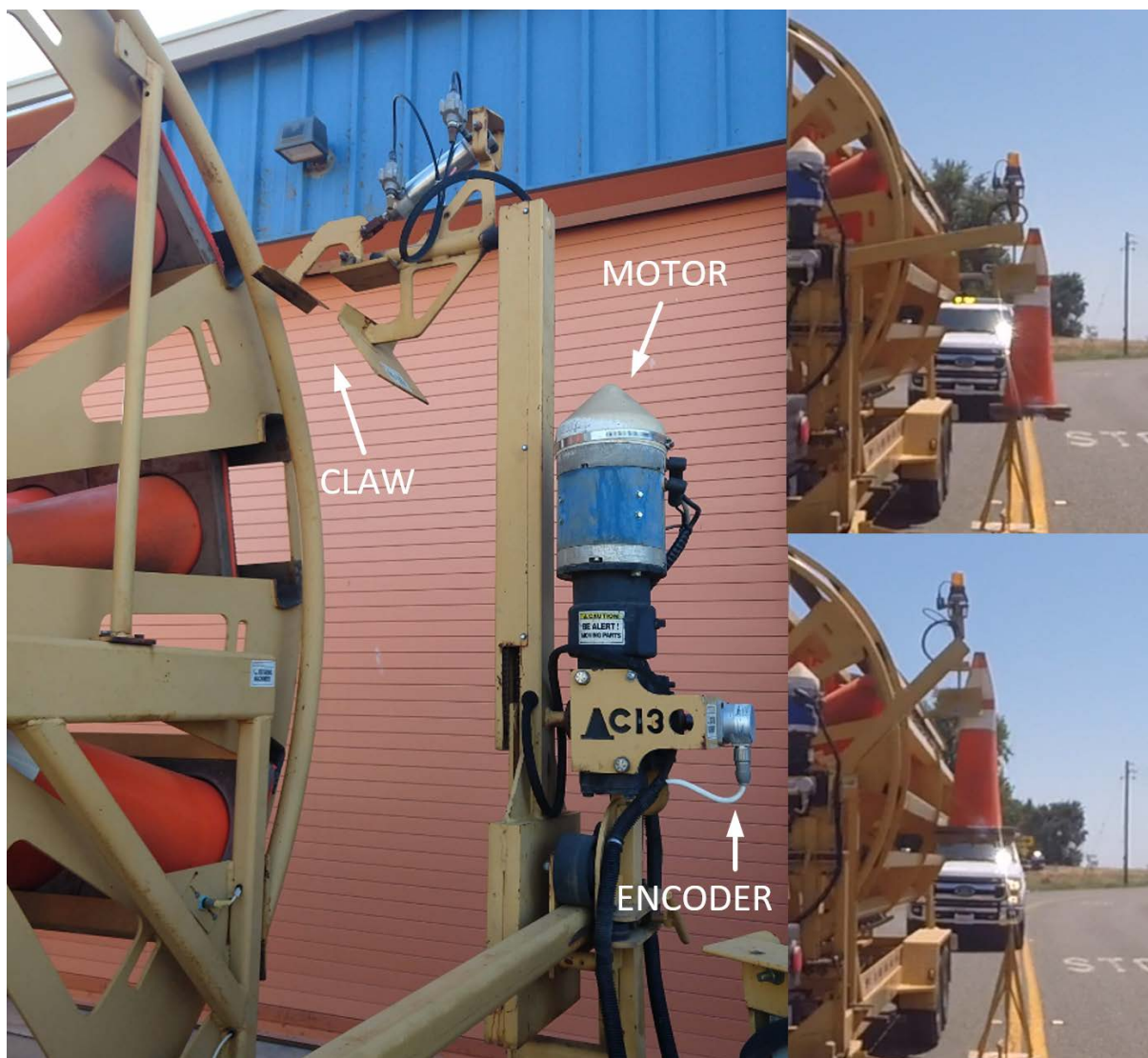


Figure 2.7: Arm and claw

Problems were experienced with the positioning of the arm on one of the machines. A failure diagnosis was not completed. The claw is able to grab the cone at various locations and will accommodate significant variations in arm positioning.

## *Retrieving Mechanism*

The retrieving system is only used when the AutoCone is retrieving the cones. As the AutoCone moves forward, cones are guided, base first, onto the retriever head. The operator then commands the retriever head to lift and rotate the cone to a vertical orientation. The arm then places the cone into the chute. Figure 2.8 shows the retrieving mechanism and the component names. The components are described below along with a description of the component setup.

### **RETRIEVER HEAD & RETRIEVER BAR**

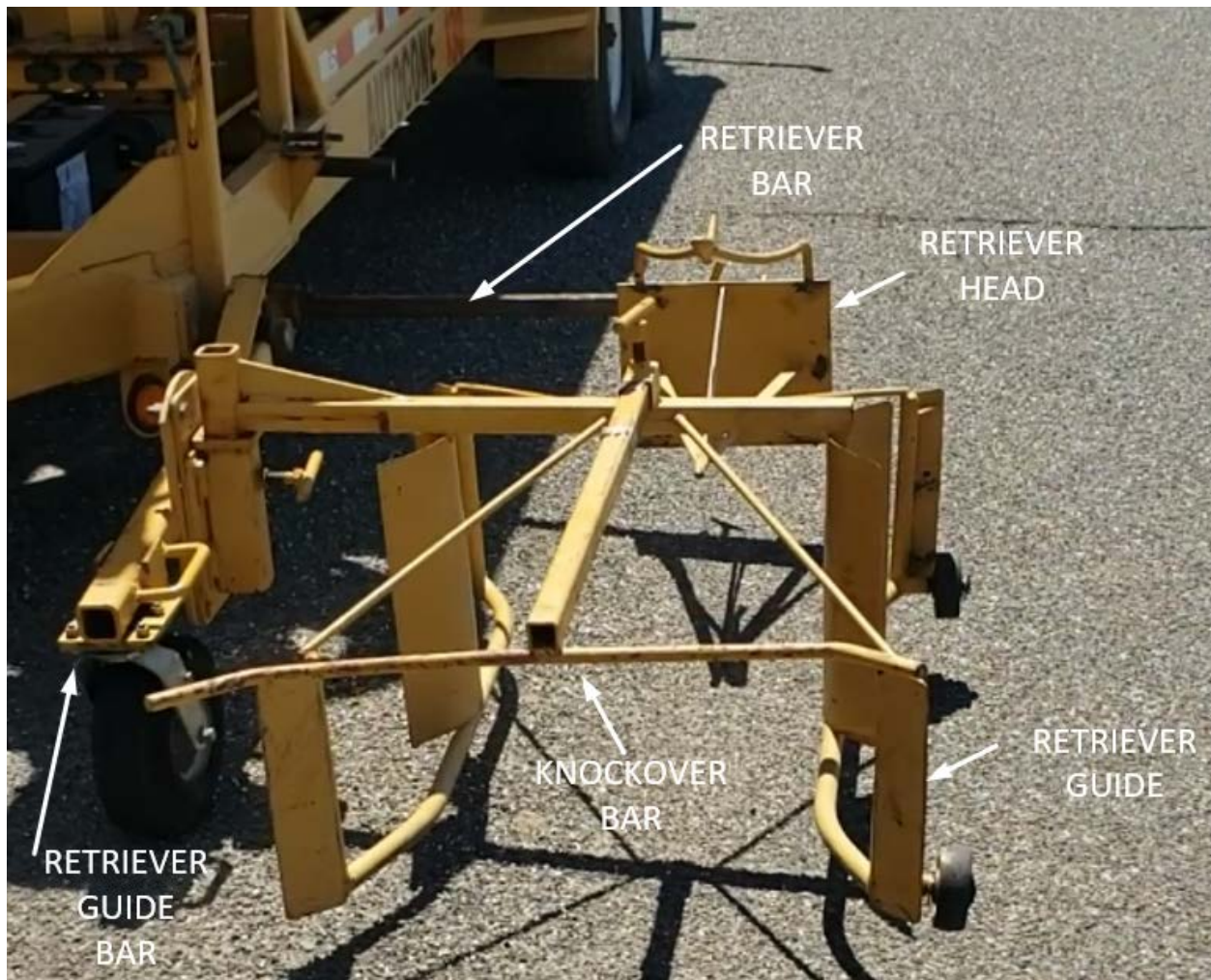
The retriever head is used to pick up a cone from the road. The arm then lifts the cone and places it in the chute to be returned to the drum. The retriever head is installed on the retriever bar. A single retriever head is used for either left- or right-side operation. The retriever head is stored at the rear of the trailer.

There are two retriever bars, one on each side of the trailer. The bars extend out of a common shaft that extends the width of the trailer. The shaft is actuated by an electric motor and rotates 90° to move the retriever head between the horizontal and vertical positions.

### **RETRIEVER GUIDE & RETRIEVER GUIDE BAR**

The retriever guide is used to guide a cone on the road onto the retriever head. The cones enter base first. The retriever guide is installed on the retriever guide bar. A single retriever guide is used for either left- or right-side operation. The retriever guide is stored at the rear of the trailer.

There are two retriever guide bars, one on each side of the trailer. The retriever guide bars are attached to the trailer with hinges and are rotated forward from the stored position to the operating position. During operation, the retriever guide bar caster wheel rests on the road to follow changes in road surface elevation.



**Figure 2.8: Retrieving mechanism**

### **KNOCKOVER BAR**

The knockover bar tips standing cones forward as they enter the retriever guide. The knockover bar is attached to the retriever guide during operation. It is removed from the retriever guide when stored at the rear of the trailer.

Problems with the retrieving mechanism can be resolved with a redesign of the retriever guide. This guide weighs almost 47 lb and is difficult to carry and handle. The retriever guide is designed to be installed on the left- or right-side. Modifying the design to optimize retrieval will require a left- and right-side guide.

## *Cones*

The AutoCone is designed to work with a 36-inch cone. Caltrans uses a 28-inch cone. Figure 2.9 shows the two different cones, and Table 2.1 compares the dimensions and weights. The AutoCone cannot accommodate the 28-inch cone without a significant redesign of several components.



**Figure 2.9: 36-inch cone with weighted base and a 28-inch cone**

The 36-inch cone is used with a weight that greatly increases stability when standing on the road. The weight greatly increases the rigidity of the base, which allows a row of cones to be forced through the drum track. The weight is fastened to the cone with drywall screws.

**Table 2.1: Dimensions and weights of cones**

Physical Description	28-inch cone	36-inch cone
Height (in)	28	36
Base width (in)	14.5	14.5
Base height (in)	2.0	2.9 (including weight)
Weight (lb)	10.0	16.8 (including weight)

## *Cone Placing Operation*

The AutoCone places each cone on the road at the command of the operator or, if equipped with the option, will automatically drop them at operator-selected distances. This operation is performed in the forward direction on either side of the machine.

The arm and claw hold the cone a few inches off the road. Upon release, the cone simply lands and slides a few inches as it comes to rest. Figure 2.10 shows the release sequence and shows the cone tipping slightly. The release height is adjustable using a knob on the control panel. The optimal height is about 3 in. The operation speed is limited by the instability of the cone as it lands on the road. While testing at 8 mph at 100-ft spacing, approximately one in ten cones fell over. The cone is relatively stable at the vendor recommended speed of 6 mph. To avoid tip-overs, the operator must limit vehicle speed changes that cause the cone to swing about the tip while hanging from the claw.



**Figure 2.10: Cone placing operation**

The distance counter rolls on one of the trailer tires. The operator must rotate the counter into place and then stow it immediately before and after placing cones.

## *Cone Retrieval Operation*

The AutoCone retrieves each cone on the road at the command of the operator. This operation is performed in the forward direction on either side of the machine.

Cones are retrieved by the retrieving mechanism, and once the cone is captured on the retriever head, the operator commands the retriever head to

rotate to the cone to the vertical position. The remaining steps to return the cone to the drum are fully automated. The sequence is shown in Figure 2.11.



**Figure 2.11: Cone retrieval operation**

By tipping the cone onto its side before capturing it on the retriever head, the square base of the cone is aligned with the sides of the chute. During closures, passing traffic may knock over cones. Knocked over cones can be retrieved as long as the base can enter the retrieval guide first. Cones laying with tips

pointed at the approaching machine cannot be retrieved without manually reorienting the cone.

The operator must coordinate steering of the truck and trailer to capture the cone in the retrieving mechanism. The operator must maintain a steady speed to allow the cone to seat properly on the retriever head. The speed needs to be limited to maintain coordinated timing with the automation system.

While testing at 50-ft spacing, the cones could be picked up once every 10-12 seconds, which is equivalent to 2.8 to 3.4 mph. The limiting factor was the machine cycle time coordinated with the operator signal to the retriever. At 100-ft spacing, this is equivalent to 5.7 to 6.8 mph, and the cone cannot be captured successfully. The cone tends to bounce uncontrollably as it passes through the retrieving mechanism. The vendor-recommended 4 mph is achievable at 100-ft spacing. These are maximum speeds that do not include time to stop and index the drum.

When operating at 100°F, the cone becomes very compliant and is easily distorted. Figure 2.12 shows an example of associated jamming that occurs. The operator must exit the vehicle to unjam the cone in this condition. Figure 2.13 shows a jam that occurred at low temperature. The cone was not fully seated on the retriever head. Under higher temperatures, the tip would simply have folded out of the way. A similar problem occurred at the claw when retrieving cones.



**Figure 2.12: Normal retrieval (left) and jammed (right)**



Figure 2.13: Retriever jam at low temperature

# Chapter 3:

## Testing and Evaluation

The testing and evaluation process included various actions and objectives. A list of these actions and objectives and the associated results are provided below.

### Steps in Testing

Prior to testing and operating the machine, steps were taken to understand the machine operation to operate it safely. Upon delivery, training was provided by the manufacturer and captured on video. Manufacturer-provided documentation was used to complete Steps 1 through 9 listed below.

1. Define (understand) and document a safe operating procedure.
2. Define the control algorithm.
3. Prepare a simplified flowchart.
4. Label inputs and outputs.
5. Define beeper codes.
6. Track and define potential errors and how to diagnose them.
7. Define system reset procedures.
8. Define safe operating procedures based on the review of the control algorithm.
9. Define a training procedure for operators.

The following machine inspection and maintenance actions were taken.

10. Measured cones and the deformation of cones. Cones potentially become distorted while in the drum. This has the potential to cause jamming. Measurements were taken and the tips were within 1 in of the nominal position when standing.
11. Check and perform maintenance on AutoCone mechanism.
12. Perform maintenance on the trailer. (Take to UCD Fleet Services to service axles and brakes)

Vendor-defined specifications were confirmed. The following additional operating time specifications were defined based on testing.

- Placing Cones: The fastest cycle time including the time to index the drum is 10.4 s per cone. This implies a speed of 5.2 mph at 100-ft

- spacing. The AutoCone must come to a stop every 13 cones, and the maximum cone placing speed is limited to 6 mph to avoid cone tipping. The lane closure placing operation speed at 100-ft spacing will average 4.5 mph. Manual operations are performed at 5-10 mph.
- Retrieving cones: The fastest cycle time, including the time to index the drum, is 13.0 s per cone. This implies a speed of 4.3 mph at 100-ft spacing. The AutoCone must come to a stop every 13 cones, and the cone retrieving maximum speed is limited to 4 mph to avoid jamming the cone in the retrieving mechanism. The lane closure retrieval operation speed at 100-ft spacing will average 3.3 mph. Manual operations are performed at 5-10 mph.
  - Load machine: When loading the machine, the operator places each cone into the chute and then presses the green button on the control pendant to push the cone in the stack. Speed is limited by the rate at which the operator can feed the cone into the chute. If the operator feeds the machine as quickly as the machine operates and a second person helps move stacks of cones into reach, loading the machine will take at least 15 min.
  - Unload machine: When unloading the machine, it is operated as if placing cones. The unloading cycle time is greater than loading because the arm motion adds time to the cycle. After the cone is dropped on the ground, it has to be removed by the operator and set aside before the next one is dropped. A second person will be required for the most efficient unloading process and time. The unloading time will be at least 22 min. Persons unloading the machine must carefully coordinate actions to avoid the path of the arm.
  - Change configuration between drop and pick up: The time required to set up the funnel components, as seen in Figure 2.11, is at least 100 s. A time of 2 min should be assumed. Additional time is required to drive to and from a safe location. At least 5 min should be allocated to this.

Additional characteristics and actions are defined below:

- Arm speed: The arm speed is defined by the control system. No changes were made to the factory settings.
- Drum indexing time required between every row of 13 cones: Minimum of 29 s.
- Battery capacity and current draws of components: This was not inspected. The vendor defines a minimum of two complete cycles at low temperatures, i.e. ambient temperatures of 32-40°F. A minimum voltage operating voltage of 24.2 V is defined by the manufacturer.

- Define low-battery hazard: The manufacturer training manual warns that the machine controller will turn off before relays and the motors fail to operate. The machine can enter an undefined state in which a motor is not stopped. This is potentially damaging and a safety hazard. The controller is designed to operate as low as 21.6 V. The control system should be redesigned so that it can check for a minimum voltage and safely stop the mechanism if the voltage is not sufficient.
- Dimensions and geometry: Operating width in placing mode is 115 in. Operating width in retrieving mode is 133 in.
- Road elevation limitations in pick up or drop off: Adjustments to trailer hitch height, the retrieving mechanism, and drop height are made once attached to a vehicle. Normal changes in road elevation will be accommodated.
- Test with a pickup: The tow vehicle must be rated to tow a trailer with 10,000 lb GVWR. An electric braking system is required.
- Visibility of the system while operating: A convex mirror on the passenger side is recommended. A rear-view camera will be recommended for use on a truck-based AutoCone operating in reverse. A camera viewing the chute and arm is recommended if it cannot be viewed directly from the cab.
- Ability to pick up tipped over cones in different orientations: Ability to pick up tipped cones where the base is not pointed directly at the retrieval mechanism will be important in any redesign.
- Test operation with the 28-inch cone: The AutoCone must be redesigned to accommodate the 28-inch cone.
- Define reliability: The reliability of the machine was problematic and limited road testing with Caltrans. The failures experienced are inconsistent, but temperature effects seem to be the most likely factor. As the machine warms up, the speed of the various motor/gearbox combinations changes. This change in speed affects timing of the mechanical sequences. The drum lock mechanism must be redesigned. Reliability of the arm positioning has not been thoroughly defined. The problems identified will require design modifications.
- Identify jamming points and potential problems: Jamming within the retrieval system is the primary concern. Redesigning the retriever guide is recommended.
- Define changes needed for taking the AutoCone trailer on the road: Reliability of the mechanism must be improved. A review of the machine with Caltrans engineering is recommended.

# Chapter 4:

## Evaluation Questions and Answers

Questions from the project proposal are listed along with the associated answers. Additional observations are added in a separate section.

### Answers to Proposed Questions

A list of questions was defined as part of the project proposal. They are presented below along with corresponding answers.

1. Drop-off rate (placing cones) and pick-up rate (retrieving cones) when moving forward:
  - The cone placing speed at 100-ft spacing will average 4.5 mph (one cone every 11.4 s).
  - The cone retrieving speed at 100-ft spacing will average 3.3 mph (one cone every 17.0 s).
  - The speeds include the time to slow down, index the drum, and then return to speed every 13 cones.
2. Estimation of drop-off and pick-up rate when moving backward based on how the system operates in the forward direction:
  - If mounted on a truck and redesigned, the system operation speeds will be similar in the reverse direction. The maximum operating speed will be below what a driver can safely drive in reverse.
3. Overall event duration starting when the equipment and staff are first exposed to traffic and ending when equipment and staff are removed from traffic to gauge reduced/increased time “on the road”:
  - It will take about 33 min to place all 130 cones and 45 min to retrieve them.
4. Documentation of additional/reduced time for AutoCone 130 equipment setup and takedown before and after a cone placement event (“off road prep,” if any):
  - When placing cones, an additional 1-2 minutes will be required to move the arm into left or right position and set switches and the distance counter wheel. The distance counter wheel must be disconnected after placing cones. During retrieval, about 5 minutes should be allocated at each end to pull off the road and setup or take down the retriever system. Additional time needs to be allocated in

the yard to ensure that the system is ready to operate. A 15-minute period should be sufficient.

5. Documentation of appropriate conditions for AutoCone 130 use:

- Day/night – Caltrans requirements for reflectors and warning lights should be implemented. Additional lighting at the retrieving mechanism is recommended to improve visibility of the mechanism at night.
- Weather, including rain, wind, etc. – Ambient temperature is the primary concern. The manufacturer defines an ambient operating temperature of 32-95°F. Tests were performed between 40°F and 100°F. At low temperature, the battery capacity will be a limiting factor. At high temperature, the cones become very soft and may jam in the retrieving operation. The Caltrans cone is a higher quality cone that can be used at higher temperatures than the 36-inch cone that was tested. Further testing at temperatures above 100°F will be required. Rain is not a concern, but high winds may cause the cones to be unstable when moving through the machine.
- Facility, including conventional highways, multilane highways, and freeways – The AutoCone will operate on all roads. Shoulder width may be an issue when setting up the machine.
- Geography, including winding roads or hilly terrain – The AutoCone trailer cannot be used on sharp turns. A truck-mounted AutoCone is recommended for maneuverability.

6. Documentation of range of dimension of cone size and material supported by AutoCone 130:

- The AutoCone 130 works with 36-inch cones, while Caltrans uses 28-inch cones. A rigid cone base is required. A higher quality cone is required to avoid distortion at higher temperatures.

7. Documentation of maintenance requirements for AutoCone 130:

- The manufacturer defined the maintenance requirements. A maintenance frequency of every 90 days will be sufficient. Prior to use, a visual inspection of components is required to look for damage or obstructions.

8. Estimated cost of AutoCone 130 production since the manufacturer is no longer producing the machines:

- The cost of producing a machine is unknown.

9. Modifications needed for Caltrans Division of Equipment to mount AutoCone 130 onto a truck, if feasible:
  - Significant modifications are required to mount the AutoCone onto a truck. As part of the redesign, the machine should be modified to accommodate the 28-inch cone. Shielding of components will be required. Design requirements will be reviewed with engineers at DOE.
10. Staff feedback on operation, maintenance, improvements, and whether mounting AutoCone 130 on a truck would be preferred:
  - Based on demonstrations and discussions with Caltrans staff, a truck-mounted version of the AutoCone is required. Additional demonstrations of the AutoCone are required prior to completing staff feedback.
11. Documentation of apparent operator/user acceptance of AutoCone 130 equipment:
  - User acceptance was limited. Additional demonstrations of the machine are required.
12. Documentation of feasibility of using the AutoCone system concept within Caltrans maintenance operations:
  - Based on demonstrations and discussions, the AutoCone may be used on long bridge closures which Caltrans performs on a regular basis. The AutoCone would be used in addition to a standard cone body. The manual cone body truck would be used to place the arrow board, place warning signs, and install the taper. The AutoCone would be used to extend the closure at 100-ft spacing. The typical closure on the San Francisco Bay Bridge is 5 mi. The 130 cones on the AutoCone will close 2.46 mi.

# Chapter 5:

## Potential Future Deployment of Automated Cone Handling

In this chapter, the potential use of the AutoCone within Caltrans operations is considered and compared to the manual cone body truck and other automated systems that may be available in the near future.

### Summary of Issues in AutoCone Implementation

The AutoCone cone handling design concept meets the basic design requirement to automate the placement and retrieval of traffic cones so that persons are not required to handle the cones. When placing and retrieving the lane closure, the operator controls the machine from within the relative safety of the truck cab. This machine is probably the simplest design possible. The large rotating drum that feeds cones to the center of the truck is a unique feature that allows the design to use a minimum of actuators and mechanisms.

The negative design characteristic of the AutoCone is that the machine is very large and heavy. When installed on a truck, it will be at least 11 ft tall and the bed length will be 20 ft. It requires actuation using high mechanical forces, which are potential hazards. Significant operator training will be required, and a code of safe practices must be developed. A partial list of safe practices is included in Appendix B.

The AutoCone trailers, as tested, will not meet Caltrans needs since they cannot be used in the reverse direction. The ability to retrieve cones in reverse is critical to Caltrans operations. Retrieving a lane closure in reverse maintains the protection of the cones upstream of the cone machine. Caltrans will require a truck-mounted AutoCone machine.

The AutoCone placing and retrieving operations are significantly slower than a manual cone laying operation. Based on discussions with Caltrans, the speed is adequate.

### Caltrans Manual Cone Body Truck

Caltrans maintenance operations are required to minimize the impact of operations on traffic flow. Maintenance lane closures are typically short and require less than 80 cones. When laying a closure, the advance warning area, 1,000-ft transition area, and 1,000-ft buffer, will require less than 40 cones. The 40 additional cones will provide a working area length of approximately 0.65 mi. The typical cone body truck used in Caltrans will carry 80 cones in two rows of 40

cones as shown in Figure 5.1. The bed is 12-ft long and includes space for signage and tools.

Additional cones can be added by extending rows of cones and double-stacking the cones. If longer closures are required, a second vehicle will carry additional cones to reload the cone body truck. A Caltrans cone body truck can carry 130 cones on a 12-ft bed by double-stacking. This is sufficient for the great majority of closures. If necessary, the cone body truck can be easily refilled on-site with cones carried in a flat bed or other truck.

Using the cone body truck is relatively inexpensive, but workers are exposed to the associated manual effort of cone handling and traffic hazards. A comparison of costs is documented in the report [Automated Cone Machine Business Development Case \(http://ahmct.ucdavis.edu/pdf/ACM\\_report\\_2007-1-5.pdf\)](http://ahmct.ucdavis.edu/pdf/ACM_report_2007-1-5.pdf).



Figure 5.1: Typical Caltrans cone body truck with 80 cones

## Other Automated Machines

A brief review of the market showed that there are two new designs that will be available in the near term. Links to these machines are below. The latest report comparing the options for automation of cone placing and retrieving is a Colorado DOT report from 2017.<sup>1</sup>

The following machines are not included in the CDOT report:

- **X-CONE - Cone Management System** (<https://www.traffic-safety-services.com/en/x-cone-traffic-cone-management-system.html>)

This machine moves cones from the truck bed to the road and back using a gantry mechanism. Cones are stored in vertical stacks and handled in a vertical orientation. They are not tipped over when retrieved. It is not clear if it can be modified to retrieve tipped over cones. This machine is marketed in Europe. It has the potential to meet Caltrans' needs.

- **Highways England Co** (<https://www.motoringresearch.com/car-news/cone-laying-machines-motorways/>)

The government-owned company is developing a high-capacity automated cone machine. It appears to be designed to carry about 390 cones weighing 22 lb each. Additional information is needed to assess the value of this machine to Caltrans.

- **Centreville AutoCone 500**

The AutoCone manufacturer has designed and built several higher-capacity truck-mounted cone machines. One example is shown in Figure 5.2. In this design, the cones are stacked at least 3 deep in the drum track. Although not on the market at this time, it may be a design that could be manufactured under a licensing agreement. This may be an option to explore.

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<sup>1</sup> [LuAnn Theiss and Gerald L. Ullman, Automated Placement and Retrieval of Traffic Cones Colorado DOT Report No. CDOT-2017-07, July 2017 \(https://www.codot.gov/programs/research/pdfs/2017-research-reports/cones/@@download/file/Report%202017-07.pdf\)](https://www.codot.gov/programs/research/pdfs/2017-research-reports/cones/@@download/file/Report%202017-07.pdf)



Figure 5.2: Centreville 500-cone AutoCone

## Traffic Cone Standards

Caltrans uses a 10-lb, 28-inch cone. There are manufacturing variations in these cones that will need to be considered for automation. A specification for cones used in automated machinery may be necessary to optimize an automated solution.

The Caltrans cone, as shown in Figure 5.3, has a hard rubber base instead of the typical softer polyvinyl chloride base of the cone shown next to it. This will be necessary if used in an AutoCone design to allow the cones to be pushed in the track. Since they are not handled manually, a 28-inch cone used in automated machines could incorporate a heavier base to increase stability while standing on the road.

The tip of the Caltrans cone has a large molded groove that will help when handling the cone manually. This feature may be useful in an automated system, especially if a stacking system is devised. This will greatly improve the options for picking a cone up by its tip. The orange body of the Caltrans cone is less pliable than typical 28-inch cones. This will be an advantage when used in automated machines. It is recommended that a specification for the 28-inch cone include definition of the material properties and geometry that facilitates automation.



Figure 5.3: Cone design differences affecting automation

## Recommended Design Changes to the AutoCone

In discussion with Caltrans, a machine like the AutoCone will be useful in locations such as the Bay Bridge where Caltrans places a 5-mi closure on a regular basis. The 130 cones will be enough to add 2.46 mi. The AutoCone will be installed on a truck chassis and redesigned to handle the 28-inch cone.

The following changes are also recommended:

- Redesign to increase the cone carrying capacity.
- Redesign the retrieval system to extend and retract automatically. The operator will control this from the cab.
- Redesign the control system to allow all control from within the cab.
- Redesign or improve the system to avoid the need for the operator to command the placing and retrieval of each cone. The distance counter design must be improved so that the operator does not have to access it before and after placing a lane closure. The retrieving mechanism should actuate automatically.

- Add features to the control system to provide easier diagnosis of any problems.
- Refine the design to maximize reliability to reduce exposure of the operator during lane closures.
- Reconsider the need to pick up knocked over cones. Retrieval of only standing cones may be a viable design for the AutoCone and other machines. Since lane closures have to be maintained during the closure, the need to pick up tipped over cones may be not be necessary if cones are normally standing when retrieved.

# Chapter 6:

## Conclusions and Future Research

This research provided a thorough evaluation of the AutoCone 130. Continuing development of the design is recommended and the purchase of the two trailers will facilitate development efforts. Due to problems operating the trailers, further testing with Caltrans crews is required to obtain sufficient feedback.

The major results and recommendations are as follows:

### Conclusions and Recommendations

- The AutoCone meets the manufacturer's specifications.
- Speeds are slower than expected since the machine is regularly stopped to index the drum. The speed is considered acceptable by Caltrans.
- The AutoCone trailer cannot be used in Caltrans operation since it cannot retrieve cones while backing up. A truck-mounted system is required.
- The AutoCone must be redesigned to use the Caltrans 28-inch cone.
- A truck-mounted AutoCone 130 is not likely to be a substitute for the typical Caltrans cone body truck due to the large size and cost. The typical maintenance lane closure requires 80 cones.
- A truck-mounted AutoCone 130 is useful in locations such as the Bay Bridge where Caltrans places a 5-mi closure on a regular basis.
- The AutoCone trailer reliability must be improved before road testing proceeds.
- Reliability of any automated machine must be high to avoid exposure of personnel in the field.
- Doubling or tripling the capacity will be important to some Caltrans operations, such as the Bay Bridge closures. Unloading and reloading the AutoCone while on the road is not recommended.
- It is recommended that mechanisms and controls should be modified so that the operator does not have to exit the cab during lane closures.

## Future Work

Based on the discussions with Caltrans, the following tasks are being considered:

- Modify an AutoCone 130 trailer as necessary to increase reliability and test the machine with maintenance crews to obtain additional feedback. Technical support is required to support the machine during demonstrations.
- Review the design details with DOE engineers to assess the tasks required to mount the existing AutoCone onto a truck frame for continued Caltrans testing.
- Investigate the latest commercially available automated cone machines.
- The X-CONE can retrieve of the cones in reverse, which is important for Caltrans. It is worth investigating this commercially available cone management system to see if it is a viable alternative.

# Appendix A: AutoCone Manufacturer Brochure

Images copied from Vendor's brochure



**Centreville Manufacturing, Inc.**

*The Home of **tag-a-long** Trailers*

**Centreville, Maryland**

## **AUTOCONE 130**



This machine puts traffic cones on the road and picks them up. All that is needed is a pickup truck and driver. The operator is safe inside the cab of the truck.



**[www.centrevilletrailer.com](http://www.centrevilletrailer.com) • (410) 758-1333**

# SPECIFICATIONS

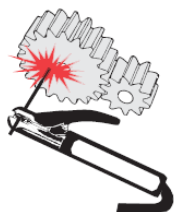
## STANDARD FEATURES

## AUTOCONE 130

- Cone Capacity ..... 130 cones
- Uses standard 36" cone with base weight and reflective collars.
- Drum Length ..... 16'
- Drum Diameter ..... 95 1/2"
- Overall Trailer Length ..... 26'-9 3/4"
- Overall Trailer Height ..... 9'-11"
- Overall Trailer Width in Transport Configuration ..... 8'
- Overall Width with Cone Pickup Guide in Use ..... 11'-3 1/4"
- Empty Trailer Weight (No Cones) ..... 7,270 lbs.
- GVWR ..... 10,000 lbs.
- Brakes, Electric (Surge Brakes Optional)
- Axles ..... Tandem 6,000 lb. EZ Lube
- Suspension ..... Leaf (Slipper) Spring
- Tires ..... 225/75D15 mounted on white 8 spoke wheels.
- Hitch ..... Adjustable height interchangeable pintle or 2-5/16" ball.
- Trailer Plug ..... 7 pin blade or 6 pin round with adaptor. Others available.

## OPTIONS

- 1) Floodlights for Nighttime Use
- 2) Auto Drop – Drops Cones at Chosen Spacing Intervals
- 3) Diesel Power Supply for Continuous Use
- 4) Digital Distance Display for Manual Cone Spacing
- 5) Rear Mounted Arrow Board
- 6) Paint Color



# Centreville Manufacturing, Inc.

*The Home of **tag-a-long** Trailers*

601 Ruthsburg Road • Centreville, Maryland 21617 • Fax 410-758-1345

**www.centrevilletrailer.com • (410) 758-1333**



The machine tows using a 3/4 ton pickup truck. No modifications are required on the truck.



The machine holds 130 standard 36" cones with base weights attached.



130 cones will cover 1 1/4 miles at 50' spacing or 2 1/2 miles at 100' spacing.



The machine will place and pick up cones from either side of the trailer. Moving from one side to another is simple and takes seconds.



The driver controls the machine using simple controls, usually just one button push per cone.



The hitch easily converts from pintle ring to ball, and provides generous height adjustments.



The entire cone storage drum rotates as needed to supply or retrieve cones. This rugged heavy duty gearbox handles the job with ease.



The optional AUTODROP package allows you to dial in a spacing distance between cones. The machine will automatically drop a cone at your chosen distance. You can change the distance during a run if you want to.



The machine will pick up cones that are still standing, or have been knocked over. The guide positions and feeds the cone where it is needed.



This pile of cones costs well over \$1000 and is a tempting target for theft. Our machine stores the cones, prevents theft, and saves the labor of constantly loading and unloading cones from trucks.



The cone hangs – waiting to be dropped on the road as you drive along. A simple button press drops the cone where you want it. The "hang height" is adjustable to accommodate road conditions and trailer hitch heights.



The machine operates on 24vdc power. The batteries shown allow the trailer to be totally self contained allowing any available truck in the fleet to do the job.



**AUTOCONE 130**

# Appendix B:

## AutoCone Safe Practices

The following points should be included in a code of safe practices for this machine:

1. Pre-op equipment. Read and be familiar with Operating Instructions as supplied by the manufacturer. Only trained persons should operate this machine.
2. Do not make any changes to the system that have not been approved by DOE.
3. Ensure that the system is fully charged prior to use. System voltage must be above 24.2 V.
4. Keep the power off unless operating the machine. Remove the key when the system is unattended.
5. Check the following before turning system power on:
  - Emergency Stop (E-STOP) is not in the stop position.
  - START/STOP is in the STOP (off) position.
  - No objects are in places that might interfere with normal operation. Chute must be empty. Look for debris that might interfere with sensors or mechanisms.
  - Drum must be correctly indexed.
  - Sensors must be clear.
6. Check that the E-STOP and START/STOP button work.
7. Do not test the E-STOP when the machine is in motion. This may cause the machine to lock up.
8. Under normal circumstances, always use the START/STOP button to stop the machine. When in doubt, press the E-STOP to prevent damage to the machine or personnel.
9. Briefly operate the machine in the yard before taking it on the road.
10. Do not use the system if a failure is detected. Use a lock-out procedure if the machine is not operating correctly.
11. The machine has several mechanisms that can cause impact or pinching injury. Before operating machine, check that no persons are nearby. Pay particular attention to the AutoCone arm.
12. NEVER approach the machine while it is operating.
13. Persons diagnosing failures must be trained to do this safely.