

California AHMCT Program
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**ASSESSMENT OF CONE PLACEMENT METHODS
AND THE DEVELOPMENT OF
AUTOMATED MACHINE SPECIFICATIONS AND
AN INTEGRATED SYSTEM CONCEPT**

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ABSTRACT

This document reports on the development of the Automated Cone Machine at the Advanced Highway Maintenance and Construction Technology (AHMCT) Center at the University of California, Davis. This application of automation has the primary objective of improving the level of safety of the traffic cone laying operation by reducing worker exposure to traffic. The assessment of the present methods of cone placement and the investigation of existing cone handling equipment have resulted in findings that have been used to develop a preliminary set of functional specifications. These specifications describe the basic capabilities of the automated cone machine concept that is being developed. The proposed automated cone machine would be designed around a modified Caltrans cone body vehicle. With the cone body configuration intact, manual operation is still possible for the few situations that cannot be accommodated by the machine. This also permits crews to use the machine with the confidence that any mechanical failure can be easily accommodated and yet it greatly reduces their exposure to the hazards of traffic. By designing as simple a system as is feasible and incorporating the cone body, acceptance by personnel will be much greater, costs will be minimized, and the transition to automation will be made much easier. Included is a summary of the initial findings, a description of the proposed machine concept, and a copy of the proposed functional specifications. These items are presented to describe the course of development that is being taken on the project.

EXECUTIVE SUMMARY

This document reports on the development of the Automated Cone Machine at the Advanced Highway Maintenance and Construction Technology (AHMCT) Center at the University of California, Davis. Included is a summary of the initial findings, a description of the proposed machine concept, and a copy of the proposed functional specifications. The application of automation has the primary objective of improving the level of safety of the traffic cone laying operation by reducing worker exposure to traffic. This is primarily achieved by placing workers within the confines of the vehicle cab when placing cones for lane closures on highways and freeways. The project activities to date include an investigation into and assessment of the present methods of cone placement and cone handling equipment, development of a preliminary set of functional specifications, and development of a concept system that will meet these specifications.

The assessment of cone placing operations was based on direct observation of the lane closure procedure, discussions with Caltrans personnel, and documentation that describes the lane closure requirements. The Caltrans cone body vehicle, a customized one ton truck, is used for most operations and is the best system available at this time, but workers placing the cones are still exposed to traffic. The basic capabilities of the cone body are considered the baseline requirements that should be incorporated into an automated system. Critical capabilities include the general versatility of the truck, particularly the ability to pick up cones in the forward and reverse directions. In addition to meeting the functional requirements, a fundamental challenge to the development of automation for this process is the need to limit costs. Since the cone laying operation usually occurs in a twenty minute period at the beginning and the end of a work shift, no economies of scale are available, and in order to consider automated machinery for general use, its cost has to be as low as absolutely possible.

Investigations of existing machinery has confirmed the commercial availability of only two machines, both of which Caltrans has previously identified. In addition to research of industry documentation and verbal inquiries, a patent search was used to identify previous developments in

automation. One of the automated systems is known as the Baliseur Cone Picker which is made in France and is a fully automated system that picks and places cones in the forward direction. It has the limitations of high cost, limited versatility, and cannot use the standard traffic cone used by Caltrans. The second machine, known as the Addco Cone Wheel, is only partially automated and still requires workers to be seated on the exterior of the vehicle. Both machines could only be considered for operations on long and frequent lane closures, which are not typical.

Based on the assessment results, functional requirements of the automated machine have been incorporated into a set of preliminary specifications that represent the capabilities of the proposed concept. Basically the automated machine operation will be the same as that using the cone body with the exception that personnel will be operating automated equipment from within the cab of the vehicle. Cones will be placed in the forward direction and picked up in the forward or reverse directions at speeds of up to 16 km/h (10 mph). The system will automatically take cones from stowage and place them on the ground at either side of the vehicle at the required interval as the driver moves the vehicle forward. Picking the cones up will be done in either direction as the driver maneuvers the vehicle alongside the cones which may be standing or knocked over. The system is required only to carry the standard cone body load of 80 cones.

To meet the basic requirements while minimizing cost, the proposed automated cone machine will be designed around a modified Caltrans cone body vehicle. With the cone body configuration intact, manual operation is still possible for the few situations that cannot be accommodated by the machine. This also permits crews to use the machine with the confidence that any mechanical failure can be easily accommodated and yet it greatly reduces their exposure to the hazards of traffic. By designing as simple a system as is feasible and incorporating the cone body, acceptance by personnel will be much greater, costs will be minimized, and the transition to automation will be made much easier.

At this stage, project development will be directed to updating the functional specifications with Caltrans input and designing critical components of the proposed concept in order to demonstrate the feasibility of these components.

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CHAPTER 1

INTRODUCTION

1.1 Background

Most highway maintenance and construction operations require a means of separating the work zone from lanes of traffic and traffic cones are one of the most efficient and most commonly used items for this purpose. Cones are available in various sizes up to 910 mm (36 in) high and are one of the most readily used markers since they will store in a very compact form and require no assembly prior to placement.

Caltrans uses the relatively common 710 mm (28 in) high cone that weighs 4.5 kg (10 lb) for traffic control operations on highways and freeways. As is typical in operations throughout the world, the cones are deployed manually. Many districts in California use a vehicle developed by Caltrans known as the cone body. The cone body is created by mounting a specialized bed to a standard truck frame, usually a heavy duty full-sized pickup known in industry as a 1 ton truck. On the cone body horizontal stacks of cones are fed by conveyor to a person sitting near ground level between the axles of the truck. The person places the cones at the edge of the truck while the driver maneuvers the vehicle as required to obtain the lane closing. Although the use of the cone body is a significant improvement over the very unsafe but common practice in which persons are placing cones off of the tailgate of a pickup, the project goal is improve the cone laying operation by reducing the exposure of the worker to traffic by incorporating an appropriate level of increased automation.

1.2 Need for Automated Cone Placement Machine

Automation of the cone handling process will provide needed improvements to worker safety by reducing exposure to the hazards of operating close to traffic and it will reduce the considerable amount of manual effort and dexterity required to place and remove cones. Cones are required to be placed close to traffic moving at 97 km/h (60 mph) or more. Traffic has to be forced over

during the cone placing operation which is inherently risky and the worker placing cones manually is forced to be within a fraction of a meter of this traffic. Persons riding on the outside of the vehicle are extremely exposed to the danger of being hit by debris and vehicles. This danger to workers continues to increase with the growing congestion in most traffic corridors. Increasing the level of automation to allow the operator to be located within the cab of the cone laying vehicle is the primary objective of applying automation to this process.

In addition to improving safety, automation reduces the physical effort involved in handling cones. A fair amount of skill is involved in placing cones off of a moving vehicle at the prescribed intervals and the repetitive motion is potentially injurious. The layout of the cone body is probably as ergonomically efficient as is reasonably possible and the use of the conveyor to feed cones to the comfortably seated operator is a good example of the improvement that is possible with even a minimal use of automation. The project objective is to improve the operation with an efficient application of automation.

1.3 Problem Description

Investigation of commercially available machines has confirmed the conclusion that no suitable automated mechanism exists for the placement of cones that Caltrans uses. Presently two cone placement machines are commercially available. These machines are known as the Cone Wheel by Addco and the Baliseur Cone Picker by SEP of France. They have been investigated by Caltrans and assessed by AHMCT and are not acceptable for reasons detailed in the body of this report. Both machines are too large and unwieldy for most cone laying operations. In addition, the Cone Wheel is only partially automated and still requires persons to be placed on the bed of the truck while the highly automated Cone Picker would require significant design modifications to accommodate the standard cones that Caltrans uses. Project goals are to develop and demonstrate automated equipment that will improve the safety of the cone laying operation, meet Caltrans requirements, and be compatible with general industry usage.

1.4 Project Status

This progress report describes the status of the initial project phases which include the assessment of present methods of traffic cone placement, review of existing devices and cones, development of functional specifications and the development of preliminary design concepts. Progress in these areas are ahead of schedule and in order to minimize any conflicts in concept development, review and approval of the proposed functional specifications is recommended.

At this stage detail design of critical components is beginning with the intent of fabricating first generation components in the next quarter.

CHAPTER 2

ASSESSMENT OF PRESENT CONE PLACING METHODS

2.1 Introduction

Various means of obtaining an understanding of the cone laying procedures have been employed to establish the requirements for automation and a summary of the resulting assessment is provided in the following sections. Opportunities to be eye witnesses to the cone laying operations were provided by Caltrans personnel at the West Sacramento maintenance yard and at District 2 near Redding, CA. As is to be expected, information provided by personnel directly involved in the operation has been extremely valuable.

2.2 Lane Closure Configuration

In order to visualize and define the basic requirements of a lane closure, the cone laying pattern and procedure for a freeway lane closure has been selected by the project as the representative configuration of a lane closure and is described below. Benefits of automation are most apparent for the setting of lane closures on freeways or highways because they use the greatest number of cones and the traffic danger is high. Since Caltrans will be the initial user of an automated machine and its procedures for cone laying are fairly standard, no further investigations into the detailed methods of cone laying operations in different states are being considered at this time.

Chapter 5 of the Caltrans Traffic Manual defines the various traffic control schemes required for construction and maintenance work zones. Details of the sign placement and cone spacing are defined in the manual but the actual sequence in which the work is carried out is not specified. All lane closures are begun from either the outside edge of the road or the center median and merge towards the center of the road. The pattern of cone placement is described below.

Advance Warning Area - Four warning signs are placed on the shoulder at 213 to 305 m (700 to 1000 ft) apart by the cone placement crew. The first three are 1.22 m by 1.22 m (48 in by 48 in) diamond signs warning that road construction is ahead and specifying which lanes are

closed. These warning signs are made out of fabric on a metal framework that allows them to be collapsed, rolled up, and stored in tubes located at the rear of the cone body. To place each sign, the crew has to assemble it and attach it to a collapsible tripod that is weighted down with three or four 4.5 kg (10 lb) bags of sand. One traffic cone is placed at the edge of the roadway next to each sign. The fourth warning sign is a trailer mounted flashing arrow sign that is unhitched from the cone body and placed on the shoulder. This flashing arrow sign is preceded by a set of four cones that have been placed at 15 m (50 ft) intervals at the edge of the road.

Transition Area - A taper that merges traffic over is begun at the flashing arrow sign and extends a minimum of 305 m (1000 ft) per lane, a lateral distance of 3.7 m (12 ft). Cones are placed at a maximum of 15 m (50 ft) intervals which requires at least 20 cones per lane. The angle of the taper is set by the driver and spacing is set by the person in the cone body who places cones across from the Bott dot markers which are spaced at 14.6 m (48 ft) intervals.

Buffer and Work Area - Past the taper, the cones are placed at a maximum spacing of 30 m (100 ft) at the edge of the closed lane. When possible this line of cones is located a distance of 0.3 to 0.6 m (1 to 2 ft) away from the edge of the traffic lane. This greatly reduces the chance that cones will be knocked over by vehicles that either impact the cone directly or blow them over with air turbulence. A 213 to 305 m (700 to 1000 ft) buffer area empty of equipment and personnel is required between the end of the taper and the beginning of the work site. One "Lane Closed" sign is assembled and placed at least every 710 m (2000 ft) in the buffer area. Curves or crests that limit the motorists line of site require additional lengths of lane closure. Cones extend past the work area by 30.5 m (100 ft) after which a short termination taper is optional.

To approximate the distances of 213 to 305 m (700 to 1000 ft) the driver uses the vehicle odometer and counts the increments of 2/10 mi which equals 322 m (1056 ft.). Using this basic increment of distance and the fact that cones are typically placed at intervals defined by the Bott dots, 14.6 m (48 ft), a minimum number of cones for a lane closure can be determined using Table 1.

Table 1. Distances & Number of Cones Required for Sections of a Lane Closure

Lane Closure Section	Length in km (mi)	# of Cones
Advance Warning Area	0.97 (0.6)	7 cones
Transition Area for one lane	0.32 (0.2)	23 cones
Transition per additional lane	0.32 (0.2)	22 cones
Buffer Area	0.32 (0.2)	11 cones

An absolute minimum of 41 cones is required for the standard one lane closure and would be 1.6 km (1 mi) long. Given that the cone body is usually loaded with 80 cones, the extra 39 cones will allow for an additional 1.1 km (0.71 mi) on a single lane closure, for the length of the work zone and any additional buffer length. A two lane closure with 80 cones would leave 17 cones for 0.50 km (0.31 mi) of additional length.

Based on the above calculations and information presently available the standard load of 80 cones is sufficient for most closures. When a larger operation is involved, the load is doubled by placing a second layer of cones on the cone body conveyor which allows for almost 2.42 km (1.5 mi) of buffer and work zone.

Procedures used to set up and take down the cones out vary and are dependent on the roadway layout and traffic patterns. In most cases cones are placed with the vehicle moving in the forward direction with traffic and are picked up in reverse operating against traffic. During the cone laying operation a shadow vehicle is used to protect the cone truck and both vehicles are highly exposed to traffic when in the advance warning and transition areas. Personnel have to leave the vehicle to set up the warning signs and the flashing arrow trailer which results in about two minutes of exposure at each stop. Road shoulder width and median configuration play an important role in defining the options available for the lane closure process. Setting up on congested city freeways with narrow or nonexistent shoulders, solid barriers, and no open medians presents the greatest challenge.

2.3 Basic Cone Machine Requirements

In order to meet needs of the most common cone laying operations, an automated cone machine has to have two important features that have not yet been successfully incorporated into presently available equipment. These basic requirements are low cost and a high degree of operational versatility.

Due to the nature of the cone laying operation, dedication of a vehicle to the task is not cost effective and efficiencies of scale are not available even in an urban environment. In a typical city, several work sites on the freeways may be set up during the work shift. To minimize the impact on commuter traffic, each lane closure has to be set up and taken down after 9:00 AM and before 3:00 PM and the length of each closure is minimized. The first and last 20 minutes of the shift are dedicated to setting up and taking down the closure which would be removed as soon as the work site job is completed. Since the site work shift is relatively short and each maintenance or construction task has differing requirements on time and equipment, every site has to have a vehicle dedicated to the cone laying operation and no consideration can be given to a cone machine that services several work areas. To perform a lane closure, a vehicle is only required to carry the required number of cones and have a platform from which the worker can reach to place and pick the cones. These minimum requirements can be achieved by using a pickup truck which is still one of the most common vehicles for cone laying. After laying the cones down, this vehicle serves as a general purpose truck and is often used as the primary means of transportation by the supervisor. Although obviously a risky task, the limited commercial development of automation for cone laying suggests that most departments of transportation and contractors find any investments in cone laying difficult to justify.

Despite of the benefits of the cone body, some Caltrans districts still use a less costly option that puts the person placing cones in a basket mounted to the front end of a truck. He or she then places or picks each cone as the vehicle is guided by the driver. A free wheeling carousel onto which cones are stacked is located within reach of the worker. This carousel carries a partial load of cones and has to be filled or emptied several times during the placing or picking operation.

Cones are transported manually to and from the stacks on the bed of the truck and personnel are limited to carrying 3 cones at one time. This operation of manually transferring the cones is performed on the roadway as the carousel is filled or emptied. Although somewhat safer than riding in the bed of a pickup, the fact that this much less efficient system has not been replaced with a cone body suggests that there is a fair amount of resistance to improvements in the cone laying operation.

The second required feature for a cone machine, operational versatility, is represented by the capabilities of the cone body. The vehicle is very maneuverable, requires no setup on the road, has room for the warning signs and other required equipment, will pull the flashing arrow sign trailer, can operate in reverse, and, when not laying cones, it is easily used as a general purpose truck. The ability to pick up cones in reverse is very important and appears to be necessary for most lane closures. Although the crew can pick up cones while driving against traffic within the closed lane, in many situations it would be difficult for the cone machine to be turned around after picking up the taper. Picking cones while moving forward in the direction of traffic exposes the shadow vehicle and the cone body to traffic approaching from behind. These requirements, for example, rule out the use of a trailer mounted system, one of the earliest concepts considered because of the potential cost advantage over a truck mounted system.

Based on field observations and given the equipment presently available, the Caltrans cone body represents the state of the art cone laying vehicle for the most common cone laying operations. The two automated machines described later may possibly be of use when very frequent long closures are required on roads that have wide medians and shoulders for set up of the equipment. Any automation scheme that is considered for Caltrans needs to be evaluated against the capabilities of the cone body.

CHAPTER 3

CONE MACHINE FUNCTIONAL SPECIFICATIONS

3.1 Introduction

As a result of the assessment and concept development completed to date, a proposed list of functional specifications has been generated. The major points are discussed in the following section and a complete listing of the proposed specifications is found in Appendix A.

3.2 Machine Description

In order to maintain the greatest operational versatility at the lowest cost possible, the automation mechanism will be designed around a modified Caltrans cone body truck. The stowage and set up of warning signs would be unchanged and manual operation would still be possible in any situation that could not be accommodated by the automated equipment or in the case of equipment failure.

In order to incorporate the automation equipment and maintain the general configuration of the cone body, some modifications will be necessary. The one major modification requires that the truck frame be extended and the cone body be shifted to the rear to allow for a 406 mm (16 in) space between the truck cab and cone body bed. This extension of the vehicle is required to allow for the addition of automation equipment while maintaining the present seating and cone stowage arrangement on the cone body. The objective would be to minimize the modifications to the cone body but additional details of this modification will be developed with detail design. At this time it is expected that the cone body will have to moved back 250 mm (10 in) with respect to the rear axle and the cab to axle dimension extended 150 mm (6 in).

3.3 Operation

Operation of the automated machine will be similar to the present procedure using the cone body with the exception that the operator is situated within the cab. Personnel will still be required to exit the vehicle to place the warning signs and cones in the advance warning areas as they presently do. Once the beginning of the taper is reached, the operator would enter the cab and complete the lane closure from within the cab. The automated equipment will be capable of taking cones from storage and placing them at the required intervals. When removing the closure, the operation will be performed in the opposite sequence with the automated equipment picking cones all the way back to the advance warning area where personnel will have to exit the vehicle to remove the signs.

The automated machine will place or pick cones at a fixed distance (approximately 250 mm (10 in)) from the edge of the vehicle at either side of the cone body. Cones will be placed at speeds up to 16 km/h (10 mph) in the forward direction only and the driver is responsible for setting and maintaining the required angle of the line of cones as is presently the case. When picking cones, the driver will be required to steer the vehicle within 150 mm (6 in) of the cones and a funnel system will be used to bring the cones to the position required for the automated picking mechanism. Picking cones will be possible in the forward or reverse direction at speeds up to 16 km/h (10 mph).

A speed of 16 km/h (10 mph) is comparable to present day operations and is deemed adequate. Since the total time spent in placing or removing a standard lane closure is approximately 20 min. at the beginning and at the end of a shift, the benefits of increased speed cannot justify the added costs associated with machinery capable of operating at higher speeds. In addition, half of the time involved in the setup or removal is devoted to setting up the advance warning area. Cone laying at higher speeds would require greater power and control system capabilities and increase costs significantly.

Picking up knocked over cones presents the greatest challenge in the automated cone handling process. In addition to being required as part of the lane closure removal, picking up knocked over

cones may be required as part of the lane maintenance operation in which knocked over cones have to be stood up and returned to their original position. The automated equipment will be designed to pick up those knocked over cones which the driver can reach by bringing the vehicle along side the cone causing it to enter the funnel. Some cones, such as those that are knocked out of the closed lane, will not be accessible unless the driver chooses to maneuver the vehicle into the traffic lanes. The worst case situation would be unchanged from present day operations in that the driver or operator may be required to exit the vehicle in order to retrieve a cone, assuming safety procedures permit it. Vehicle speed will have to be reduced as required when picking knocked over cones.

Optional capabilities such as picking on one side while placing on the opposite side, placing cones on both sides of the vehicle at the same time, and varying the offset distance between the truck and line of cones have been considered during concept development. Since capabilities such as these add complexity to the automated machine and the need for these capabilities has not been presented, they will not be included.

Various levels of automation are possible, but, to reduce costs, the minimum level required to achieve the stated functional capabilities will be incorporated. A person in addition to the driver may be required to operate and monitor the cone machine from within the cab. Personnel will not need to exit the cab to set up equipment when the machine is on the road. Equipment that extends beyond the edge of the vehicle during operation will be designed to retract automatically within vehicle legal width requirements at the end of the operation. Some set up of funnels and other equipment may be required in order to change the direction of travel in the picking mode or when changing cone handling operations from one side of the vehicle to the other. This type of set up would only be required off site or within the protected confines of the lane closure prior to picking cones.

Operators will not normally handle cones during operation except to load or unload cones at the depot. Manual retrieval of damaged cones that cannot or should not be placed in stowage may be required.

3.4 Miscellaneous Requirements

Although the automated machine concept can be made to accommodate a large range of different size cones if necessary, the added cost associated with full adjust ability is not justifiable and limitations are imposed to simplify concept development. The initial prototype machinery shall handle the Caltrans standard one piece 710 mm (28 in) tall PVC cone weighing 4.54 kg (10 lb). with bases 356 to 368 mm (14.0 to 14.5 in) wide. Representative samples from different manufacturers will be accommodated and some exclusions may be required. Since cones from different manufactures may not be compatible, cones of only one type would be loaded into the machine at any particular instance. The automated equipment will not be required to handle cones with collars, loose reflective sleeving, or other variations.

Further assessment is required of the need for additional cone carrying capacity beyond that of the standard cone body. The stowage system shall be capable of holding a minimum of eighty cones which is the present cone body single layer load. Design of a double layer stacking system will be considered an optional capability.

If manual operation is required, the change over will be simple but operation of the automated equipment while a person is seated in the cone body bucket is not to be a standard operating mode. Some interference between non-operating stowage equipment and manual access to the stack of cones from within the bucket seat is acceptable.

CHAPTER 4

INVESTIGATION OF EXISTING MACHINES AND CONES

4.1 Introduction

Continued research of previously developed cone handling equipment has confirmed the existence of only two automation systems, both of which have been previously investigated by Caltrans. Several sources of information have been used including a patent search, reviews of road construction trade journals, and inquiries with vendors and users of cones. Based on the previously detailed assessment of the Caltrans cone laying methods, it has been concluded that these machines cannot meet the functional specifications. Patents were found on both these machines and an additional concept not commercially available. Descriptions of the patent search and the machines found are detailed below. Also included is a summary of the investigation required to define the properties of the various traffic cones available.

4.2 Patent Search

A patent search was conducted to find more information about the different mechanisms that have been used for the handling of cones. The Derwent World Patent System was accessed at Shields Library at the University of California Davis to search through international and recent U.S. patents. This system references almost seven million patent documents by class numbers but it can only supply the patent abstracts. The search was able to locate the Cone Wheel Dispenser and Collector, patent number 5054648, which is currently produced by Addco, a Canadian company, and is in use in at least six states. The CASSIS System was then used to find a complete listing of all pertinent patent abstracts registered in the United States. In conjunction with the CASSIS system, the Official Gazette of the United States Patent and Trademark Office was referenced. With this list of patent numbers, a two-phase search was then possible. The first

phase was to examine the abstracts for each listing at the Shields Library Government Documents Department and the second phase was to retrieve the complete patent from the State Library in Sacramento. From this search, two cone related patents were found. One device was the Baliseur Cone Picker, a complete vehicle produced by SEP in France and patented in the United States under patent number 4597706. This design accomplished retrieval, storage, and dispensing of cones. The other patent was for an older mechanism called the Traffic Cone Retriever, patent number 3750900. The Traffic Cone Retriever was designed only for the retrieval and storage of cones. The complete patents of all three of the previously mentioned devices describe in detail the mechanisms that make each unit unique.

The first patented concept in cone retrieval was issued in 1973 as the Traffic Cone Retriever but no evidence of its production has been found. It operated while driving forward at a claimed speed of 56 km/h (35 mph). This device had two revolving paddle wheels that were positioned side by side at the front of the vehicle. These wheels picked up only standing cones and transferred them to a conveyor that carried the retrieved cone upwards and rearwards to the storage area. Cone storage was accomplished by a vertical stacking system which accommodated multiple stacks of cones and promised a carrying capacity of 1500 to 2000 cones. This extreme carrying capacity was achieved by generating one stack at a time, then releasing the entire stack which then traveled down a gently sloped bed to the rear. These multiple stacks could be positioned laterally to maximize the use of space in the bed. This design is impractical since it only addresses the picking up of standing cones and cannot meet most of the requirements for an automated cone machine.

In 1986 the French Baliseur Cone Picker was issued its U. S. patent. This machine is a more complete apparatus than the older Traffic Cone Retriever in that it not only retrieves and stores cones, but it also dispenses them. Fully automated, the machine is controlled from within the cab of the truck, operates at 18 km/h (11 mph), and can retrieve both standing and fallen cones. To recover standing cones, the Baliseur tips them over and orients them so that the base of the cone faces to the rear. Traveling forward, the vehicle then picks up the cone by placing a prong into the hole in the base. The prong and cone then travel upwards and rearwards on a chain link conveyor

to the storage area. Fallen cones with tips pointing forward are easily retrieved in the same fashion. Cones that have fallen and are oriented with the tips pointed to the side are reoriented to face forward with a simple funneling system. Cones pointing to the rear are tumbled end over end to ultimately face forward using a retractable tipping bar. This tipping bar engages the top of the base of the fallen cone to cause it to tumble. Once oriented by the funnel system, the cones are lifted by the prongs on the conveyor.

Cones are stored by dropping them from the top of the chain link conveyor into a vertical chute. The cones are stacked in an assembly of 10 vertical cylinders that rotate about a vertical axis. The assembly indexes to allow the cone dispenser access to each cylinder, as required, and has a storage capacity of 240 cones.

A dispenser system below the two rearmost cylinders separates and removes each cone from the bottom of the stack. The dispensed cone falls to the ground where a flexible skirt stabilizes it. The cone is then released to the desired lateral position. Both of the rearmost cylinders can dispense simultaneously or independently.

Caltrans has investigated the feasibility of using the Baliseur in California and the primary problem with this machine is that it will only handle custom cones delivered with and specifically designed for use with the machine. Although the outer dimensions are similar to the Caltrans cone, in order to operate correctly with the Baliseur machine, the cones have to meet strict specifications with regard to dimensions, weight, stacking characteristics, and material properties. SEP, the manufacturer of the Baliseur, has determined that the system will not handle the cones that Caltrans uses and cannot be modified to accommodate them. In addition, since the system is designed for use with a specific truck frame produced by Renault, a fair amount of design would be required to install the system on a U.S. made vehicle. As a result, Caltrans cannot use this system without extensive changes in cone specifications and hardware changes. Even if these issues could be resolved, the machine itself would only be cost effective for operations in which very long and frequent lane closures are required.

The third patent for cone machines was issued in 1991 for the Addco Cone Wheel. This semi-automated machine utilizes a large wheel to both dispense and retrieve cones to and from an operator seated on the bed of a truck. This wheel consists of two conical disks about 1.2 m (4 ft) in diameter that hold the cones by wedging them between the discs. The mechanism is mounted to the side of a truck and can operate at 32 km/h (20 mph). To dispense cones the operator drops each cone into a small chute located above the wheel. As the cone falls, it is placed on the road surface by the rotating action of the wheel. A stripping bar frees the cone from the wheel to ensure proper placement. For retrieval, the standing cones are run over with the wheel. Each cone is lodged between the disks and as the wheel rotates, the cone is rotated upward. When the cone reaches the top of the wheel, a stripping mechanism separates it from the wheel, allowing the operator to remove and stow the cone.

Evaluations of the Cone Wheel have determined that this machine will not meet Caltrans requirements. Although basically a sound concept under controlled conditions, this method of handling the cones is not effective because of the variations in cone dimensions and properties. Cones that are knocked over cannot be picked up and the mechanism is susceptible to being jammed. Excessive set up requirements, potential jamming of the machine, and its bulkiness make the present method of cone placement with the cone body much more desirable. Significant manual effort is required and personnel must be placed on the road to deploy and retract the system. Since personnel continue to be exposed to traffic and have to manually handle the cones, there is no advantage to using the Cone Wheel machine.

4.3 Traffic Cone Description

In order to be compatible with as many cones as possible, a wide selection of 710 mm (28 in) cones were obtained from vendors. The design of traffic cones is very much non-standardized and manufacturers have limited available documentation. Some customers have requirements that require certification to some material standards but usually purchase specifications are limited to requirements in weight and height while other dimensions are not specified. Requiring a specific

geometry, such as base height and width dimensions, will very likely limit the selection of vendors and require expensive mold changes. Although the cone angle varies between manufacturer's, stacking incompatibility between cones does not seem to be a problem for manual operations but obviously can create havoc with automated equipment.

The cone Caltrans uses is a standard 710 mm (28 in) high and weighs 4.5 kg (10 lb). Cones are generally available in heights of 305, 457, 710, and 914 mm (12, 18, 28, and 36 in) with the larger ones used on roads with high speed traffic. Although the 710 mm (28 in) cone is available in a 3.2 kg (7 lb) version, Caltrans and many other customers purchase the 4.5 kg (10 lb) version which is more stable and less likely to be blown over by passing traffic. Most of the cone is molded out of an orange polyvinyl chloride (PVC) plastic and the extra weight is obtained by thickening the walls of the conical section and the base. The bottom of the bases are usually gray and include small pads that elevate the bottom surface about 19 mm (0.75 in) off the road. Some cone laying operations use weighted collars to add weight at the base of the cone.

Variations in geometry and material properties can have a significant impact on the design of automation equipment. As an example, the Baliseur cone picker has a dispensing system that cannot be modified to handle the Caltrans cone. Although the dimensions and weight of the Baliseur cone are similar, the much more compliant PVC material of the Caltrans cone cannot be accommodated without a major redesign of the machine.

PVC is the more common material but its mechanical properties are extremely temperature dependent and the cones are only rated for a temperature range of -12° to 66° C (10° to 150° F). At high temperatures the cone is extremely compliant and the conical section can easily be collapsed with a few Newtons of force whereas the cone becomes hard and brittle at low temperatures. Rubber cones with better temperature properties are available for approximately twice the cost, \$22.00 retail cost, but the temperature range is increased to -40° to 93° C (-40° to 200° F).

Cones were obtained from a variety of manufacturers by contacting vendors and distributors. The vendors were queried regarding the source of the cones and the manufacturers listed in the following table were identified. Standard 710 mm (28 in) cones were purchased from each and

basic dimensions and mass properties tabulated below were measured and calculated for design purposes. With the exception of the unusual polyethylene Plastifab cone, the cones are manufactured out of PVC plastic and range in weight from 3.2 to 4.5 kg (7 to 10 lb). Cones from Traffic Safety Services and A&B Reflectorizing are most similar to the cones used by Caltrans and they have base dimensions of 368 mm (14.5 in) or less. Since additional cone base width increases the extension of the modified cone body, the 368 mm (14.5 in) cone base width is being used as the nominal design dimension. Cones from Lakeside Plastic and American Barricade appear to be not used by Caltrans and, since the base dimensions are approximately 394 mm (15.5 in), they will not be used for design of the prototype cone machine.

Table 2. Physical Properties of 710 mm Traffic Cone

Vendor Cone Weight	Height of Cone mm (in)	Mass of Cone kg (lb)	Width of Base mm (in)	Height of CG above ground mm (in)	Y-axis Moment of Inertia kg m ² (lb in ²)	Z-axis Moment of Inertia kg m ² (lb in ²)
Traffic Safety Services 4.5 kg (10 lb)	688 (27.1)	4.43 (9.75)	366 (14.4)	116 (4.57)	0.141 (483)	0.099 (339)
Traffic Safety Services 3.2 kg (7 lb)	699 (27.5)	3.52 (7.75)	363 (14.3)	142 (5.61)	0.130 (444)	0.071 (242)
American Barricade 4.5 kg (10 lb)	711 (28.0)	4.54 (10.0)	389 (15.3)	134 (5.27)	0.169 (576)	0.100 (343)
American Barricade 3.2 kg (7 lb)	719 (28.3)	3.18 (7.00)	389 (15.3)	143 (5.63)	0.117 (398)	0.061 (210)
A&B Reflectorizing 4.5 kg (10 lb)	699 (27.5)	4.77 (10.5)	358 (14.1)	113 (4.44)	0.152 (520)	0.108 (370)
A&B Reflectorizing 3.6 kg (8 lb)	711 (28.0)	3.52 (7.75)	378 (14.9)	123 (4.83)	0.126 (432)	0.080 (275)
Lakeside Plastic 4.5 kg (10 lb)	724 (28.5)	4.86 (10.7)	394 (15.5)	119 (4.70)	0.172 (589)	0.117 (399)
Lakeside Plastic 3.2 kg (7 lb)	711 (28.0)	3.31 (7.30)	394 (15.5)	135 (5.31)	0.126 (431)	0.073 (251)
Plastifab 3.6 kg (8 lb)	699 (27.5)	3.75 (8.25)	356 (14.0)	85 (3.35)	0.112 (383)	0.092 (316)

CHAPTER 5

DESIGN AND CONCEPT DEVELOPMENT

5.1 Introduction

Concept development was begun with brainstorming sessions followed by concept design and then evaluation. Many iterations of this process were used to identify all possible means of placing, picking and stowing cones. Cone picking has proven to be the most critical operation due to the difficulties inherent in handling knocked over cones. In the initial stages, all possible vehicle platforms were considered which allowed consideration of many options that were evaluated with a design trade-off selection process. When the design requirements used in the trade-off evolved to consider the benefits of mounting the machine to the cone body, the concepts were further reduced to the five listed in Trade-off #2 of Appendix B. At this stage, the critical capability of picking cones was evaluated in conjunction with placing and stowage on the cone body.

At the final trade off, placing and stowage concepts were defined to the level necessary for incorporation into a system concept. Placing of cones is achieved relatively simply by dropping the cone to the road through a chute. Using appendages of various types, such as rubber flaps, the cone is stabilized and exits the chute as the truck moves forward. Stowage involves the transfer of the cone from the picking device at the side of the truck to the center where the cone is tipped over and placed into stack lying horizontally. A system of belts is used to transfer the cone to the middle and the transition to the belt from the side is the primary interface to the picking system.

All the picking concepts required a funneling system to bring the cone to a controlled position and orientation necessary to allow a relatively simple mechanism to pick it up. The extreme limitations on cost ruled out the use of more sophisticated sensor systems or complicated mechanisms such as a robotic arm to pick and place cones. Various funneling configurations have been evaluated and tested as part of the development of picking methods and two basic designs evolved, one in which cones are fed into the picker standing up and one which oriented the cones base first similar to the Baliseur Cone Picker.

The concept known as the Rotating Prong, concept # 2 of the trade off, was selected for further development. This concept tips over each cone and picks it up with the prong placed in the opening at the base. By tipping cones over, a simple funnel system can be used since previously knocked over cones only have to be oriented base first and not stood up. This concept is relatively simple, robust, and maximizes the ground clearance. Details of the funnel systems, the selected concept, and the other trade off concepts are found in the following sections.

5.2 Funneling System Design

Funneling of the cones is required to orient them in a configuration necessary to pick them up. When removing cones from a closure, most cones will be standing but an estimated 10 % will have been knocked over by traffic. To pick cones up, the driver is expected to bring the vehicle alongside the cone and into the funnel system which then orients the cone as required for the pick up system. Standing cones are relatively simple to handle but the knocked over cones may lie in any orientation. Minimizing the components of the funnel system is important since it must be capable of retracting mechanically and is difficult to mount to the truck in the area of the cab. For picking purposes, two systems of funneling evolved. The first funnels cones to the picker in the standing position and knocked over cones are stood up using passive and active components. The second design, the one used with the selected rotating prong concept, funnels cones to the picking mechanism base first by tipping them over if standing and then orienting them. A semi-active mechanism activated by the operator is required to flip cones over when they approach tip first. Funnel design concepts continue to be developed to optimize operation and stowage.

Three types of components are used in the funnel systems and can be set up in different sequences. As described in the sequence shown in Figure 1, they are the tipping bar, the funnel and the flipping wheel.

The tipping bar can be used to tip over a standing cone or flip over a knocked over cone approaching tip first. To flip a cone, the tipping bar is set to catch the top edge of the base of the

fallen cone which stands the cone up. If moving quickly, the cone continues to rotate past the standing position and falls over into the base first position.

The funnel is used to guide the cone into position. Funnel designs will vary depending on what orientation the cone approaches it. In the configuration shown in Figure 1, which sets cones in the standing position, the funnel guides and orients the cone so that the base is placed squarely on the retrieval mechanism. Any cones coming in roughly base first can be guided like this. Cones coming in roughly tip first will have been either stood up or oriented base first at this time by the tipping bar. Standing cones are centered by the funnel using the secondary recurved portion of the funnel which rises above and curves in further than the primary funnel. This ensures that the conical portion of the cone is used to position the cone without interfering with the cone base.

The star shaped flipping wheels are the final items of the funnel system shown in the figure. The flipping wheels are a pair of powered paddle wheels that flip a fallen cone oriented base first into the standing position as it passes by. These wheels rotate rapidly so that as the top edge of the base of the cone is encountered, the force on the cone due to the wheels is enough to tumble the cone into a standing position. These wheels are separated to allow standing cones to pass between them unaffected but are close enough to properly engage the bases of tipped cones.

Many funnel system configurations are possible and the final design must consider factors such as stowage space, mounting requirements, and ground clearance. By using a retrieval method with cones tipped over and base first, the secondary portion of the funnel and the flipping wheels can be omitted which simplifies the funnel system.

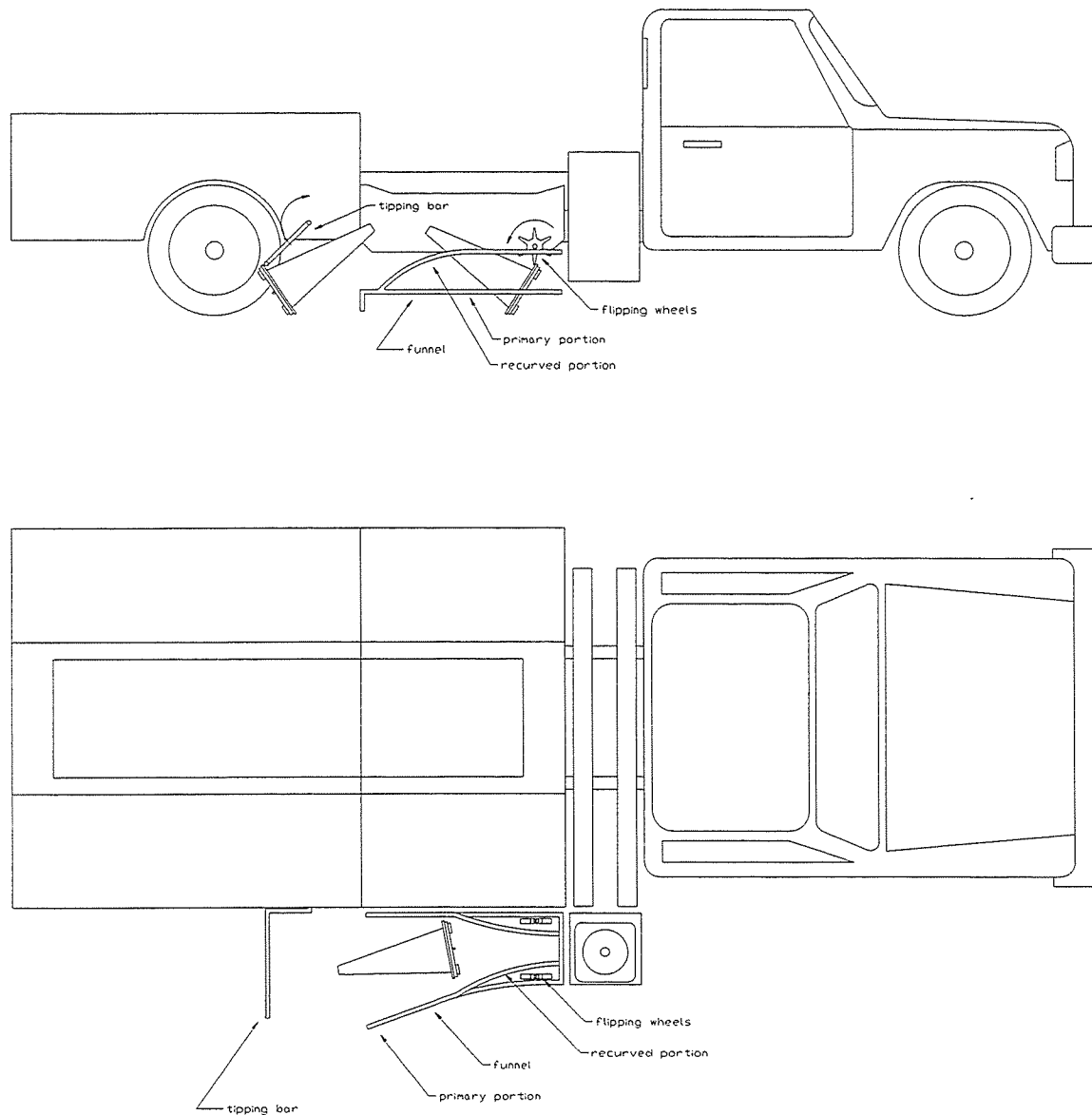


Fig. 1 Funnel components shown on funnel system used to stand cones. Vehicle is moving to the left.

5.3 Selected Concept

The selected automated cone machine concept uses the rotating prong to pick cones. This concept is the optimum configuration that will meet the cone laying operation requirements previously assessed. Given the constraint on costs and the need for a versatile but effective

system, the incorporation of the this automated machine onto the cone body is the most likely to succeed. Shown in Figure 2, the basic operation is described below.

This machine retrieves traffic cones by manipulating the cones into a base first orientation. The funnel system forces the cones into one of three initial orientations: base first cones, tip first cones, or standing cones. Once oriented, the cone enters a funneling area to positively position the cone laterally. When approaching knocked over cones that are oriented base first, the funneling mechanisms allows the cone to proceed to the pick up area untouched. For tip first cones, an adjustable tipping bar located on the side of the vehicle contacts the top of the cone base. With the vehicle traveling at a slow speed, the cone will be tipped and remain standing. For all standing cones, a second tipping bar contacts the cone just below its tip and knocks it over into the base first orientation. After the cone has been properly oriented, it is then retrieved.

An arm mechanism retrieves the cone by entering the exposed base side of the cone with a prong. The prong arm lifts and rotates the cone upwards to a vertical position. This motion is executed by a rotary actuator that is attached to the side of a boxed chute. The cone is placed at the top of the boxed chute where two options are available. The cone can either be dropped back onto the road as needed during lane closure maintenance or the cone can be dropped onto the conveyor and sent to the storage area.

After the cone is raised above the boxed chute, the cone is transferred to an extendible conveyor system which moves the cone to the storage area. The conveyor belt runs laterally and moves the cone to the center of the truck where a mechanism transports it into one of the horizontal cone stacks. These storage stacks index forward or backward as required. For development purposes a single layer two stack system will be developed.

In the placing operation, cones are fed from the stacks at the center of the truck to the conveyor which carries them to the boxed chute. The extendible conveyor is retracted into a position that allows the cones to be dropped through the boxed chute at regular increments of distance along the road. The cones fall through the chute and exit towards the rear as the vehicle moves forward.

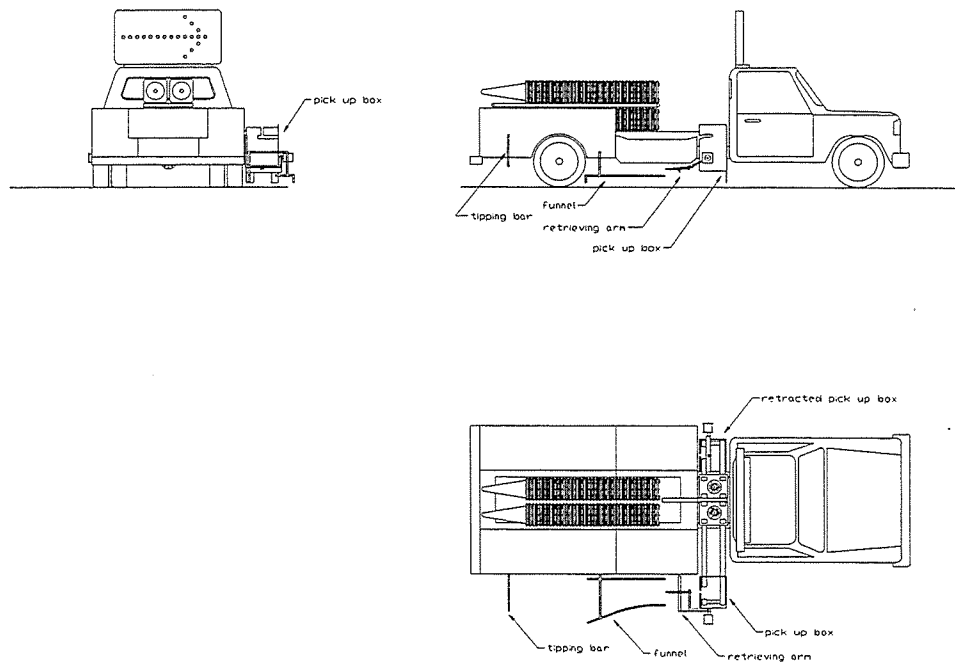


Fig. 2 Concept 2 with rotary prong selected for further development.

5.4 Other Trade-Off Concepts

Trade-Off Concept 1 - Diagonal Lift

The diagonal lift method differs from the other concepts in that the mechanism used to pick up the cones operates as a continuous process. This minimizes the automation control required and is potentially less costly and less prone to failures. A funneling system requiring the flipper wheels to stand up knocked over cones is required since the cones are picked up in the standing position. Figure 3 shows a cross sectional view of the picking system. To pick the cones a motorized auger brush would pull the cone into the area behind the cab against a motorized belt. The action of the friction roller and spring loaded brush would lift the cone up to the ribbed belt which transports it to the top of the bed. The cone would be placed vertically at the center of the truck and then tipped into the horizontal stack. When placing cones the system would run in reverse with the spring loaded brush wheel lifted off the belt.

Potential disadvantages include minimal ground clearance, limited stowage space for the mechanism itself and possible problems with contamination that might reduce the friction force at the roller. The minimal space available limits the design options such as angle of the conveyor belt or location of the auger and potentially may complicate the design.

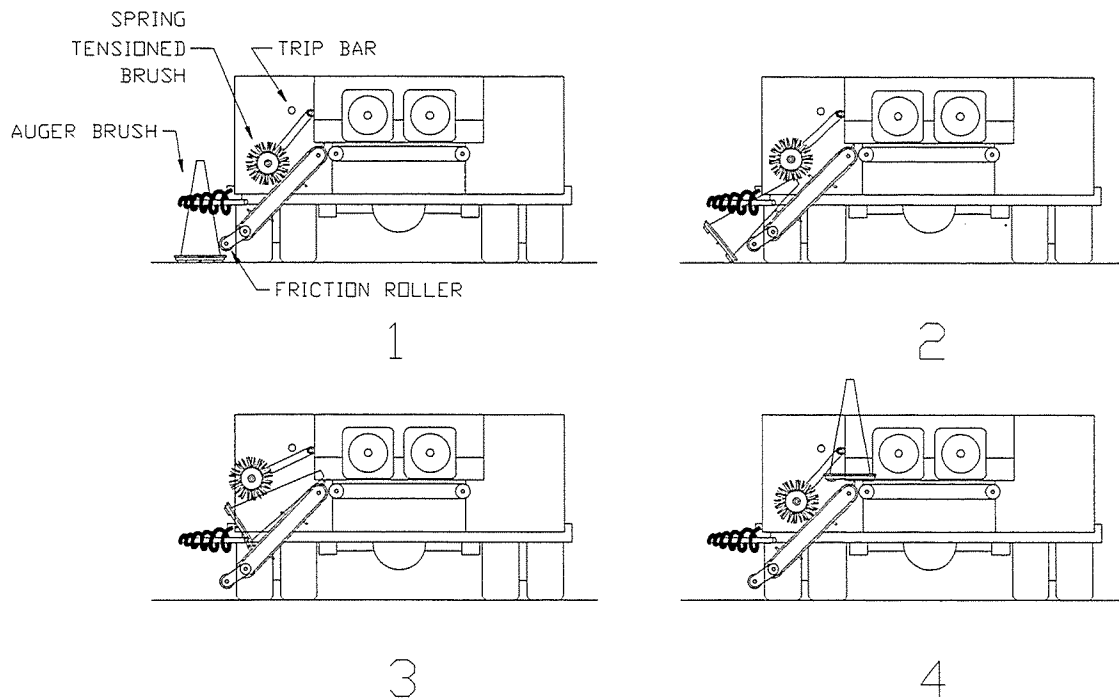


Fig. 3 Concept 1 - Diagonal Lift Method. Cross section view at the rear of the cab looking aft. Funnel is not shown.

Trade-Off Concept 3 - T.H.E. with Chain Drive Retrieval

The trade off concepts 3, 4, and 5 use what is described as the Tip Hop and Elevate (T.H.E.) method of cone retrieval. In this method a standing cone is lifted and set onto a flat plate by slightly tipping the cone to lift the near edge of the base. When released by the tipping mechanism which moves past the cone, the cone appears to hop onto the plate which is located to catch the cone as it falls back to the standing position. Since such a simple means of getting the cone on a plate would simplify retrieval, this method of restraining the cone was investigated further. Results showed that the cones could not be lifted onto a plate more than 50 mm (2 in) above the

road without assistance of a powered mechanism such as the cleated track shown in Figure 4 which helps to pull the tipped cone onto the plate. In this concept, a chain driven, elevating device then lifts the cone and places it within the confines of the cone body where it may be stowed away. The elevating prong is a two piece folding bar which is free to fold in one direction in order to minimize the area that it sweeps while locking in the other direction to elevate the cone. The contour of the box assists in elevating the cone as well as providing for the proper configuration for cone dispensing.

The advantage of this picking method is that the T.H.E. action necessary to restrain the cone is relatively passive and actuation required to bring the cone up to the belt is limited to turning the chain drive on and off. Disadvantages include limited ground clearance and a somewhat complex chain drive and prong assembly. The general space restrictions would make stowage of the mechanism difficult and possibly interfere with the placing mechanism.

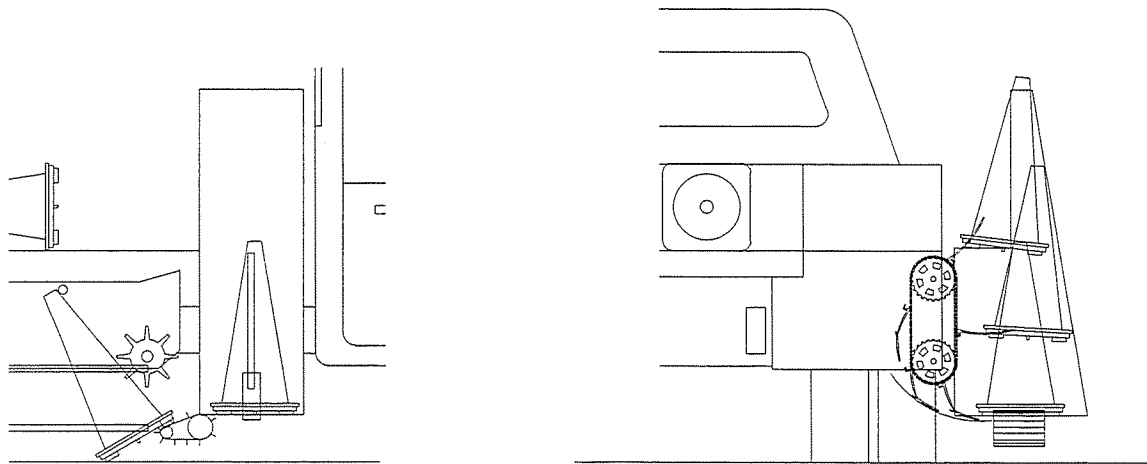


Fig. 4 Concept 3 - T.H.E. with Chain Drive Retrieval. Side view shows tip hop and elevate action. End view shows cone being raised to truck bed.

Trade-Off Concept 4 - T.H.E. with Actuator

This concept uses the previously described T.H.E. method to capture standing cones. Once on the plate, the linear actuator raises the plate and cone to the bed of the truck where the cone is transferred to the conveyor belt and then stowed.

As in concept 3, the advantage of this picking method is that the T.H.E. action necessary to restrain the cone is relatively passive but it also includes the disadvantage of limited ground clearance.

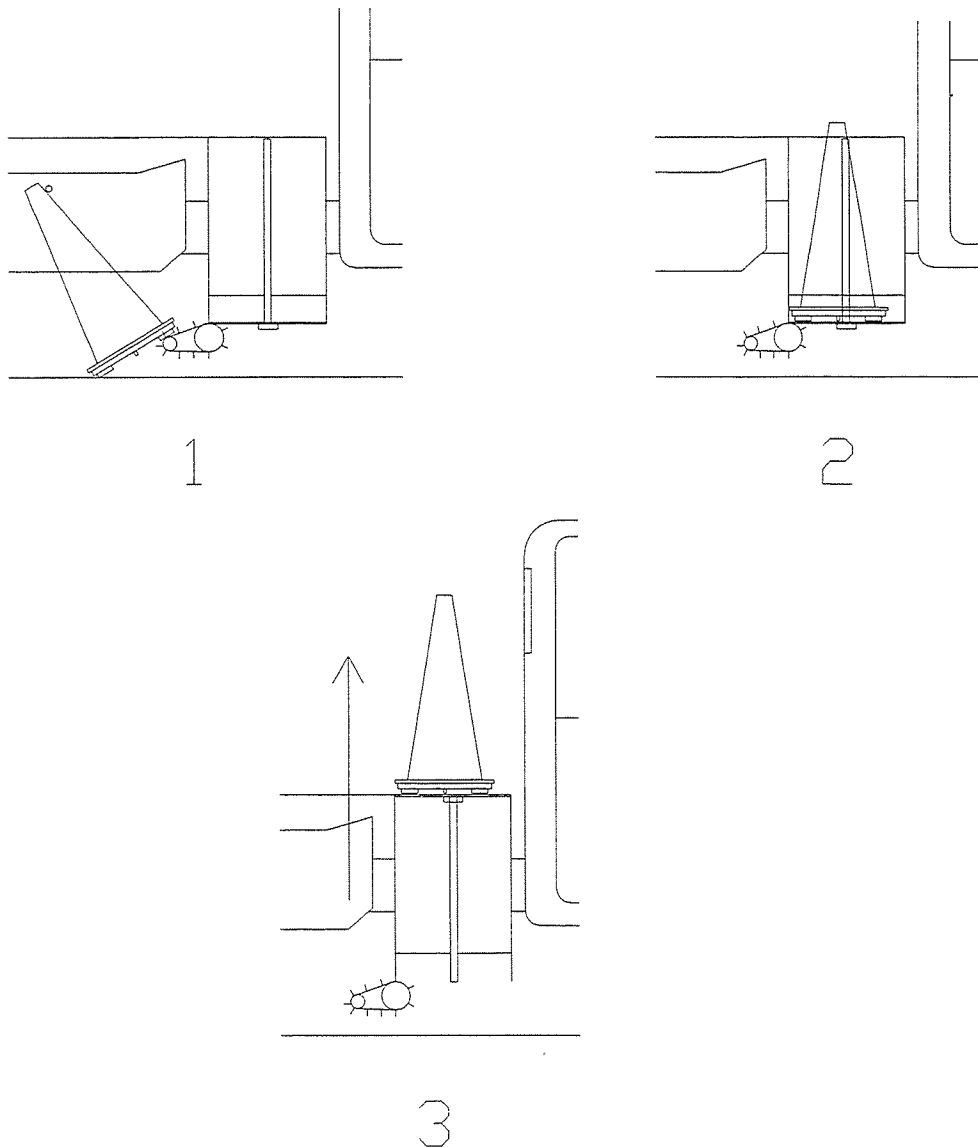


Fig. 5 Concept 4 - T.H.E. with Actuator

Trade-Off Concept 5 - Plate with Prong

The Plate with Prong Retrieval Method starts by funneling all the cones into a base first orientation. The prong enters the cones through the opening in the base and a bumper is used to properly square the cone. The prong then lifts the cone in an arc until it lands firmly on a slotted plate. The slot allows the prong to travel through the plate and position the cone at the plate's center. A linear slide then raises the plate to the bed level of the truck and the cone is pressed against two narrow conveyors that run laterally. The cone travels into the vehicle and is squarely oriented by use of a wall that contacts one side of the cone base. The cone is then ready for stowage.

Similar to concept 2, it has the advantage of using the simpler funnel system which brings cones in base first. Disadvantages include the use of a second actuator necessary to raise the cone to the bed and the lower ground clearance resulting from use of the wheel.

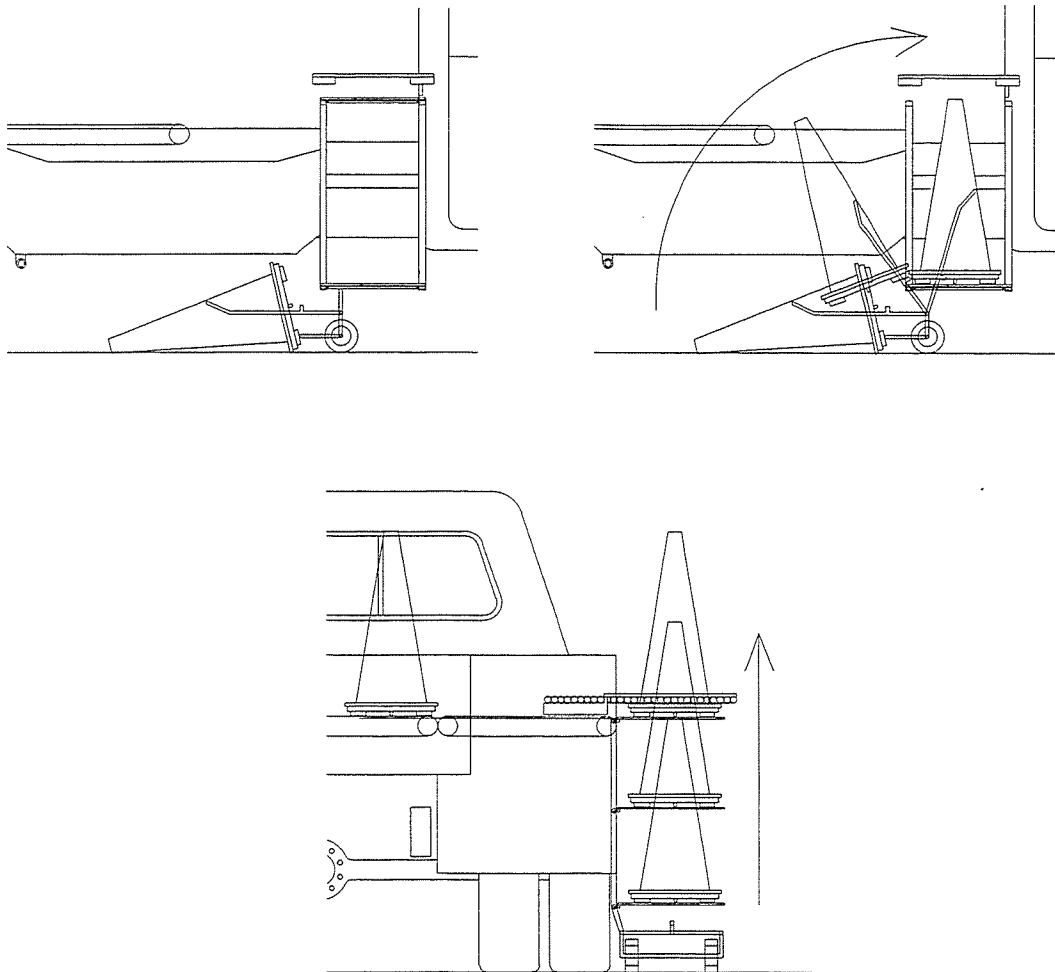


Fig. 6 Concept 5 - Plate with prong retrieval method. Side views show prong entering base and lifting cone onto the plate. End view shows plate raising cone to truck bed.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment of the cone laying operations and the design concept development to date, the continuing course of action will be directed towards incorporating automated equipment onto the Caltrans cone body. This configuration meets the primary objective of removing the operator from the bed of the truck and placing him or her within the confines of the truck cab when placing cones. With the cone body configuration intact, manual operation is still possible for the very few situations that cannot be accommodated by the machine. It also permits crews to use the machine with the confidence that any mechanical failure can be easily accommodated and yet it greatly reduces their exposure to the hazards of traffic. By designing as simple and easy to use system as is feasible and incorporating the cone body, acceptance by personnel will be much greater, costs will be minimized, and the transition to automation will be made much easier.

Work in the following quarter will be directed to the design of critical components used for the cone picking operations and an initial review of the functional specifications. Critical components of this system are the prong and arm assembly used to remove the cone, the drop chute that places the cone onto the road, and the funnel system which orients the cone before it reaches the picking system. Fabrication and testing of the first generation prototypes will be pursued as quickly as possible to prove the concepts and allow for continuing optimization of these components. To support development and testing without purchasing a truck at this time, the project is attempting to obtain a used cone body which will be cut up to use as a trailer test bed.

Review of the preliminary functional specifications by Caltrans will continue the process of assessing the cone laying operation needs. Issues such as optional modes of operation, proposed modifications to the cone body, cone base size, and cone stowage quantity need to be addressed and finalized.

APPENDIX A

PRELIMINARY AUTOMATED CONE MACHINE FUNCTIONAL SPECIFICATIONS

The following is a proposed specification that describes the general operational requirements of the Caltrans automated cone machine. It describes the basic capabilities of the proposed concept machine being developed at the AHMCT Center.

1.0 MACHINE DESCRIPTION

The machine is to assist human operators in the placing and picking of traffic cones in Caltrans operations as they are presently performed with the primary objective of increasing safety by reducing exposure of the operator to traffic. This is achieved by keeping the operator within the confines of the cab and using the necessary machinery to handle the cones.

In order to maintain the greatest operational flexibility possible, the automation mechanism will be designed to be mounted onto a modified Caltrans cone body 1 ton truck which will allow manual cone laying operations if necessary. In order to accommodate the automation equipment and maintain the general configuration of the cone body as it is presently designed some modifications will be necessary. The one major modification requires that the truck frame be extended and the cone body be moved to the rear to allow for a 406 mm (16 in) space between the truck cab and cone body bed. This is necessary to allow for the use of the seating and cone stowage arrangement that Caltrans has been using.

2.0 OPERATION

Details of operation are as follows:

2.1 Placement of Cones

The automated machine will place cones to either side of the cone body as is presently done. Cones will be placed at speeds up to 16 km/h (10 mph) in the forward or reverse directions. Cones will be placed at a fixed distance (approximately 254 mm(10 in)) from the edge of the vehicle at

intervals of 15 m (50 ft) or 30 m (100 ft). As is presently the case, the driver is responsible for setting and maintaining the required angle of the line of cones.

2.2 Retrieval (Picking) of Standing Cones

The automated machine will pick standing cones at either side of the cone body as is presently done at speeds up to 16 km/h (10 mph) in the forward or reverse directions. The driver will be required to steer the vehicle within +/- 152 mm (6 in) of the cones and a funnel system will be used to bring the cones to the position required for the lifting mechanism.

2.3 Retrieval of Knocked Over Cones

The automated machine will pick up knocked over cones which the driver can reach by bringing the vehicle along side the cone causing it to enter the funnel. Operator interaction by means of a switch will be required to signal the machine if a cone is entering the funnel base first or point first. Vehicle speed may have to be reduced when picking knocked over cones.

2.4 Lane Maintenance

The machine will be capable of changing between the pick and place mode to allow for the operator to retrieve and replace cones that have been knocked over in a standing lane closure. Operation will be similar to the retrieval mode in that the driver is responsible for maneuvering the vehicle as required to pick up a knocked over cone or place a standing cone. Operator interaction by means of a switch will be required to signal whether a cone is being placed or picked and if a cone is entering the funnel base first or point first.

2.5 Optional Operations

Operations such as picking on one side and placing on the opposite side have been considered. Since this capability will increase the level of complication of the automated machine and the need for this capability has not been presented, it is not a requirement.

2.6 Level of Automation

A person in addition to the driver may be required to operate and monitor the cone machine from within the cab.

Operators will not normally handle cones during operation except to load or unload cones at the depot. Manual retrieval of damaged cones that cannot or should not be placed in stowage may be required. Some setup of the machine may be required depending on the operating mode and direction of travel selected but this would be done away from traffic.

Equipment that extends beyond the legal width requirements of the vehicle during operation will be capable of being retracted mechanically without requiring the operator to exit the cab. Personnel will not be required to exit the cab to set up equipment when the system is on the road.

Application of automation applies to the handling of cones only and placement of warning signs will continue to be performed manually as is presently done.

3.0 MISCELLANEOUS REQUIREMENTS

3.1 Cone Configuration

The machinery shall handle the standard one piece 4.5 kg (10 lb) PVC cone that is presently in use by Caltrans. Cones from Traffic Safety Services and A&B Reflectorizing are most similar to the cones used by Caltrans. The cones have base dimensions of 368 mm (14.5 in) or less and the prototype machinery will be designed around this dimensions. Samples from other manufacturers will be accommodated but some exclusions may be required. The equipment will not be required to handle cones with added collars or loose reflective sleeving.

The stowage system shall be capable of holding a minimum of eighty 710 mm (28 in) cones (present cone body single layer load). Design of a double layer stacking system will be considered but considered an optional capability.

If manual operation is required the change over will be simple. Operation of the automated equipment while a person is seated in the cone body bucket is not to be standard. Some interference between non-operating stowage equipment and manual access to the stack of cones from within the bucket seat is acceptable.

APPENDIX B

TRADE-OFF TABLE #2

The following table was used to compare the five concepts described in the report. The mandatory design considerations are checked against each concept. Other design considerations have a weight factor from 1 to 5, 5 being most important. A value of 1, 2, or 3 times the factor is recorded under each concept depending on how well the design meets the design requirement. The optimum design will have the highest total.

DESIGN CONSIDERATION	Factor	Concept 1 Diagonal Lift	Concept 2 Rotating Prong	Concept 3 THE w/ Chain	Concept 4 THE w/ Actuator	Concept 5 Plate w/ Prong
1. MANDATORY CAPABILITIES						
a. Places moving forward		√	√	√	√	√
b. Picks up moving forward		√	√	√	√	√
c. Picks up moving backward		√	√	√	√	√
d. Operates at left or right sides		√	√	√	√	√
e. Operates at 3-16 km/h (2-10 mph) minimum (Cones standing)		√	√	√	√	√
f. Picks up within +/- 152 mm (6 in)		√	√	√	√	√
g. Spaces cones automatically		√	√	√	√	√
h. Installs on CALTRANS cone body		√	√	√	√	√
i. Driver controlled speed		√	√	√	√	√
j. Handles generic 710 mm (28 in), 4.5 kg (10lb) cone		√	√	√	√	√
k. Easy to load manually		√	√	√	√	√
l. Simple conversion to manual operation		√	√	√	√	√
2. OPTIONAL CAPABILITIES						
a. Pick & place same side moving fwd for lane maintenance.	5	10	15	5	5	5
b. Pick & place opposite side moving fwd	5	10	10	10	10	10
c. Pick & place same side moving backward for lane maintenance	3	6	9	3	3	3
d. Pick & place opposite side moving backward	3	6	6	6	6	6
e. Change operating direction quickly for lane maintenance	1	1	1	1	1	1
f. Maintain lane with funnel and flipper system.	1	2	0	2	2	0
g. Operates at 0-3 km/h (0-2 mph) (Cones standing)	4	8	8	4	4	8
h. Operates at >24 km/h (15 mph) (Cones standing)	2	2	2	2	2	2
i. Operated by driver only	1	2	2	2	2	2
j. Ejects defective cones	1	0	0	0	0	0
k. Placing mechanism can be set laterally to 0.68 m (27in)	2	2	4	4	4	4
l. Placing mechanism is continually adjustable to 0.68 m (27 in) with actuator	2	2	4	4	4	4
m. 80 cones per layer	4	8	8	8	8	8
n. Leaves flag storage area unmodified	1	2	2	2	2	2
3. SYSTEM DESIGN CONSIDERATIONS						
3.1 Funnel Requirements						
a. No funnel required	5	0	0	0	0	0
b. Can use funnel without flipper wheel or tipping bar.	5	0	0	0	0	0

c. Can use funnel without flipper wheel	5	0	10	0	0	10
3.2 Vehicle Requirements						
a. Mounts to cone body w/ no major modifications	5	0	0	0	0	0
b. Mounts to cone body w/ 406 mm (16 in) extension or less	3	6	6	6	6	6
c. Mounts to rear of cone body	3	3	3	3	3	3
d. Modular and compatible w/ standard trucks	3	3	6	6	6	6
e. Minimal rear view obstruction	4	12	8	8	8	8
3.3 Stowage Requirements						
a. Compatible with cone body stacking methods	5	10	10	10	10	10
b. Compatible with vertical stacking etc.	1	2	0	2	2	2
4. GENERAL DESIGN CONSIDERATIONS						
a. Meets minimum road clearance of 102 mm (4 in) with support wheel	4	8	12	4	4	4
b. Meets minimum fixed road clearance of 152 mm (6 in)	5	5	10	5	5	5
c. Requires no support wheel	5	5	10	0	0	0
d. Positive control of cone (incl. 45 degree orientation)	3	6	6	3	3	6
e. Scrubbing of cone < 1.2 m (4 ft) per deployment	2	4	4	4	4	4
f. Compatible w/ variations in cone geometry & material properties	5	10	10	10	10	10
g. Compatible with debris (water, sand, tar) on road	5	5	10	10	10	10
h. Durability & maintainability	3	6	6	6	6	6
i. Rotary joints only	3	6	6	6	0	0
j. Minimum of actuators	3	9	6	6	6	6
k. Minimum of sensors/control	3	9	6	3	3	3
l. DC electric power only	3	6	3	3	3	3
m. Quick change to manual operation	3	6	6	6	6	6
n. General safety of machinery	5	10	5	10	10	10
o. Safety of person in bucket during operation	4	8	8	8	8	8
o. Safety to traffic	5	10	10	10	10	10
p. Minimal set up of equipment	5	10	10	10	10	10
q. DMV width limits maintained during non operation	5	10	10	10	10	10
r. General flexibility & modularity	4	8	12	8	8	8
s. Aesthetics	5	10	10	10	10	10
t. No patent infringement issues	5	10	5	10	10	5
POINT TOTAL						
	124	258	279	230	224	234