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**DESIGN CONCEPTS FOR INCIDENT CLEARING
IN AUTOMATED HIGHWAY SYSTEMS***

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FOREWORD

This report provides design concepts and information for the development of servicing vehicles to clear incidents on Automated Highway Systems (AHS). The design concepts presented are based on existing information on AHS configurations as part of studies related to operational assessment of AHS facilities.

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Abstract

This report provides design concepts and information for the development of servicing vehicles to clear incidents on Automated Highway Systems (AHS). The design concepts presented are based on existing information on AHS configurations as part of studies related to operational assessment of AHS facilities.

1 Introduction

The field of Automated Highway Systems (AHS) is a very diverse area of research. This report concentrates on the means to clear a roadway incident to minimize traffic disruption and maximize roadway throughput. Removing roadway incidents in a timely manner is of prime importance due to increased traffic density on the AHS. In this report, a "roadway incident" is defined as any type of failure in the automobile that causes the automobile to stop responding to commands from the AHS control computer. Examples of faults include: electronic faults such as automobile computer controller failure, and mechanical failures such as flat tires or malfunctioning engines. Furthermore, any type of vehicle accident is considered a "roadway incident." Since the automobile cannot respond to commands from the central computer, a "servicing vehicle" must be dispatched to retrieve the malfunctioning automobile. This report considers different types of servicing vehicles ranging from manually operated to semi-automatic to fully autonomous. Each of the design concepts is based on preliminary AHS design information available at this time.^(1,2) As more AHS information becomes available, it is expected that the servicing vehicle concepts will become more complete.

2 Automated Highway Systems (AHS) Assumptions

Since AHS design information at present is only preliminary, several assumptions have been made regarding AHS capability. These assumptions are made to facilitate the analysis needed to prepare design concepts for the Roadway Servicing Vehicle (RSV). The assumptions made include: incident reporting capability, lane isolation, lane placement, and vehicle modification requirements.

Incident Reporting Capability

It is assumed that AHS will have the ability to perform lane closure and status reporting under an external controller command. AHS configurations reviewed to date indicate that this capability is considered reasonable and can be considered as a sound assumption about system capability. The status reporting capability of AHS is considered especially important since many of the designs detailed later in this report depend upon status information to locate the incident.

Isolated Lanes

Due to the autonomous nature of AHS, it is assumed that non-autonomous and autonomous vehicles will not be mixed in the same roadway lane, but be operated on separate special roadway lanes. Some of the design concepts presented later assume further isolation and that a barrier or wall is used to physically separate the autonomous/non-autonomous lanes.

Lane Placement

It is envisioned that the AHS roadway lanes would be retrofitted into today's existing roadways in the same fashion as today's carpool lanes and bus ways. Thus, the AHS lanes would most likely be placed in the number 1 lane position to minimize interference with entrance and exit ramps. AHS vehicles could enter the automated lanes by several different methods. They could enter by simply asking the roadside computer for access, or they could first enter a transition lane where they would begin communication with the roadside computer. Three separate configurations of an AHS are shown in figure 1.

Specially Designed Vehicles

Since the AHS roadway provides enhanced capability, vehicles traveling along the road must be modified with AHS technology to take advantage of the roadway's capability. In addition, the authors assume that the vehicle's design can be sufficiently modified to allow for a method of efficient removal from an incident. The amount of design modification to the vehicles will depend on the final configuration of the RSV.

3 Design Considerations

This RSV system study is based upon several design requirements and constraints. These include: problem description, operational requirements, safety requirements, and operational scenarios.

Problem Description

The goal of this design report is to develop several concepts for systems to remove stalled, disabled, or damaged vehicles from an AHS roadway lane. The types of systems under consideration are (1) manual, (2) semi-automatic, and (3) fully automatic. To minimize response time, each of the RSV's will operate within a designated service area along a portion of AHS roadway.

Operational Requirements

The primary operational design requirement for the RSV is the ability to operate and be integrated within the AHS framework. This includes compatibility with computer and data information exchange, as well as general mechanical compatibility with the AHS infrastructure. An example of data compatibility is the ability of the RSV computer system to identify the roadway incident location from the AHS computer status reports. Mechanical compatibility defines design characteristics such that the RSV must stay within AHS roadway weight limits and over-crossing height limits.

Preliminary AHS reports indicate that different classes of vehicles (i.e., different weights, sizes, etc.) will operate in AHS lanes. Therefore, the design concepts for the RSV must be able to handle the different classes of vehicles.

Lastly, in order to minimize the cost of AHS vehicles, a minimum of modifications should be made to the vehicles to accommodate the servicing procedure of the RSV. The locations of existing hard points of the AHS vehicles will be used whenever possible to guide the design of the attachment fixture of the RSV.

Safety Requirements

For safety reasons, the RSV will operate with the occupants still inside the car. At no time will the vehicle occupants be required to leave the vehicle during the entire servicing procedure. Occupant interaction with the RSV will take place through the vehicle's on-board computer or communication system. Additionally, the RSV must not obstruct or hinder the normal operation of the AHS lane. Thus, once the RSV has serviced the disabled vehicle, the RSV and the disabled vehicle must be able to travel at near normal speeds to the nearest servicing station.

Operational Scenarios

RSV stationed in roadway median at specific intervals

Once the AHS computer system has located an incident, the AHS central computer will dispatch the RSV from its designated base station (figure 1). The RSV will then travel to the incident site and service the roadway incident. The method of vehicle service will depend on the design of the RSV. For example, some design concepts involve lifting the entire vehicle onto the RSV, other involve just towing the disabled vehicle. The RSV and disabled vehicle will travel together as a unit to the nearest designated service area. Once there, the occupants may disembark from their vehicle and contact the proper agencies to repair their vehicle.

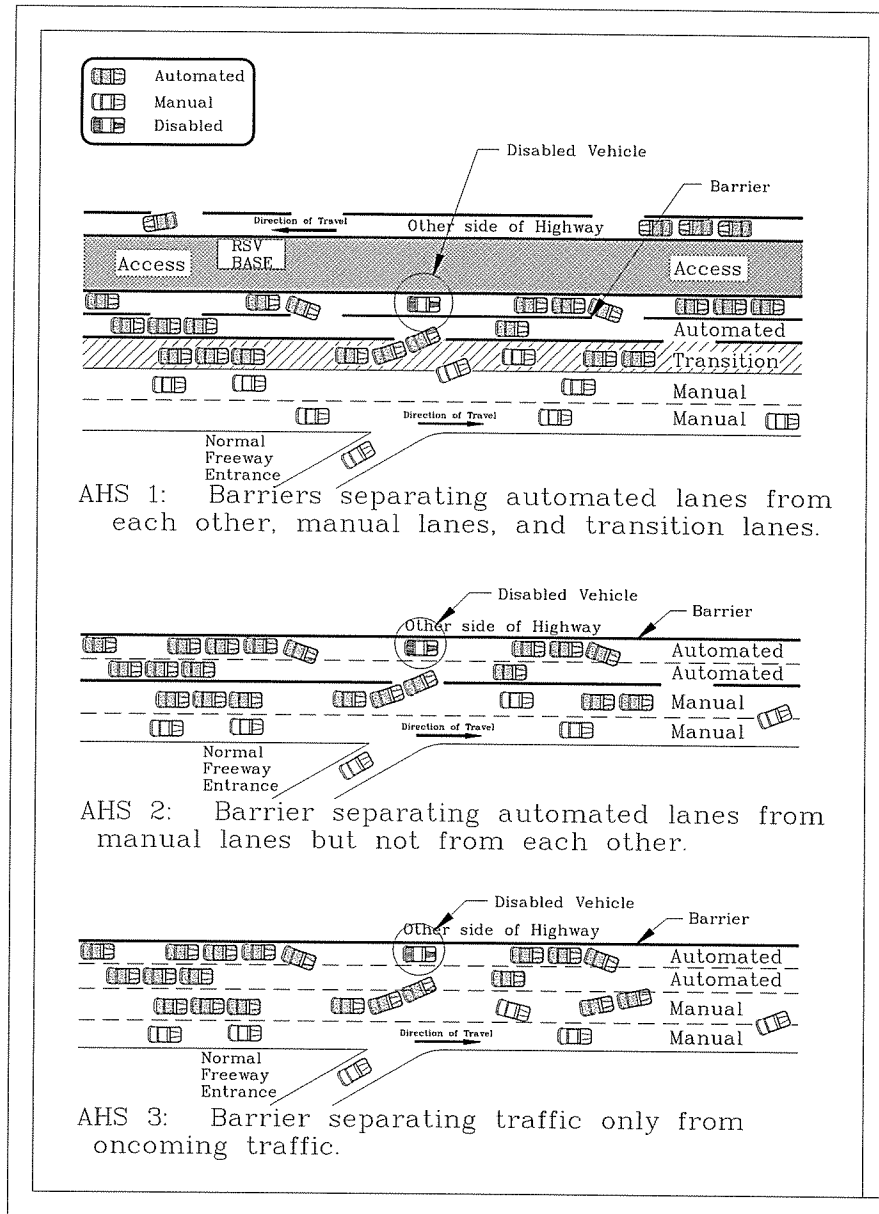


Figure 1: Some current configurations of an AHS

Roving RSV scenario

In this operational scenario, the RSV would patrol a stretch of designated AHS roadway. The RSV would constantly circulate along the roadway looking for incidents to service. When the RSV either contacts a roadway incident or is notified of one by the AHS central computer, the RSV would service the disabled vehicle and remove it to a service area. The RSV would then return to its patrol area and continue operating.

RSV as part of the infrastructure

In this operational scenario, the RSV would be built in as part of the infrastructure of the AHS. For example, the RSV could be contained within the roadway barrier and activated when needed. This design would insure high availability of the RSV and allow the road to be cleared very quickly.

4 Design Concepts

Several design concepts have been developed in the following pages. These include: Manual RSV, Movable Barrier RSV, Over Barrier RSV, Flatbed RSV, Barrier Mounted RSV, and a combination of two of Movable Barrier and the Manual RSV's.

Manual Roadway Service Vehicle

This concept is the most primitive of systems considered in this report. The manual RSV's would be operated part-time by human attendants and be little more than present day tow trucks (figure 2 & 3 & 4) modified to use the AHS system. Attachment systems would consist of the Eagle Claw stinger recovery systems in use today. The system's main advantage is that little new technology, other than AHS equipment, would have to be developed to make it operational. Additionally, the AHS vehicles would not need to incorporate interfaces and structural modifications to accommodate this RSV.

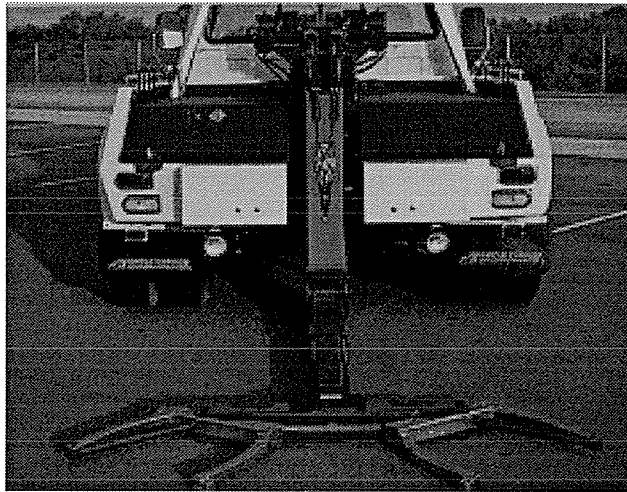


Figure 2: Tow Truck with Eagle Claw hook up

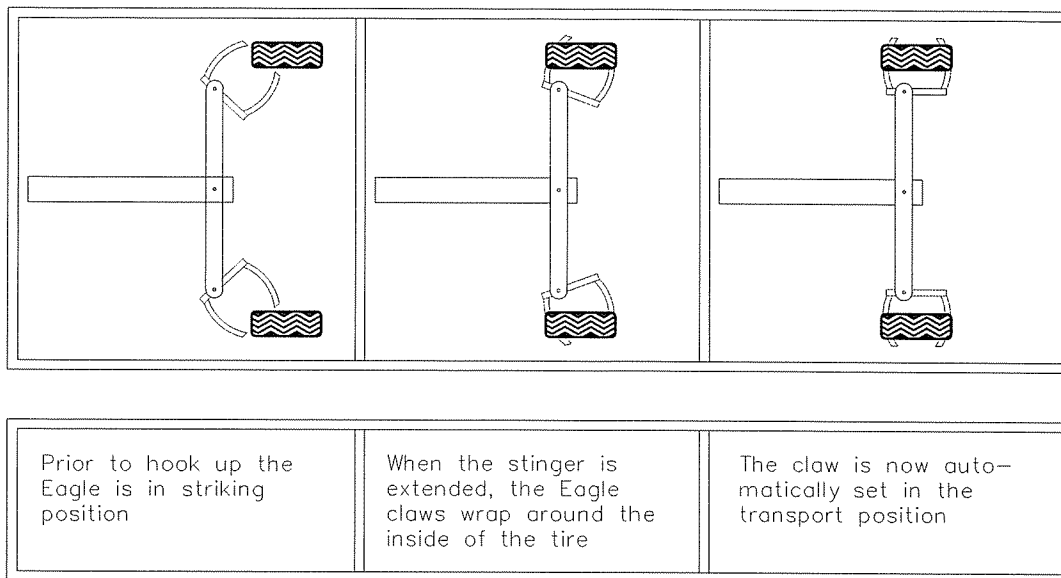


Figure 3: Eagle Claw method of hook-up

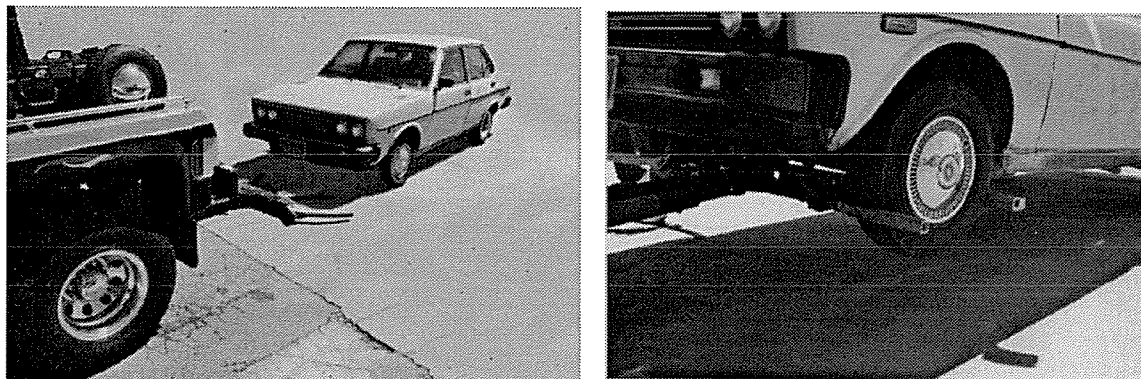


Figure 4: Actual Eagle Claw Tow Truck in use today.

Movable Barrier RSV

Initial deployment plans of AHS indicate that Jersey-type barriers will be used for AHS lane isolation. By incorporating a lifting mechanism into the barriers (see Appendix A), roadway incidents can be cleared almost immediately. Once the AHS central computer detects an incident, the barrier closest to the incident would deploy (figure 5). Lifting forks would rotate down then move underneath the disabled vehicle. Wheels would then deploy from beneath the barrier (figure 6) and then move the disabled vehicle/barrier unit from the AHS lane to the access lane (figure 7).

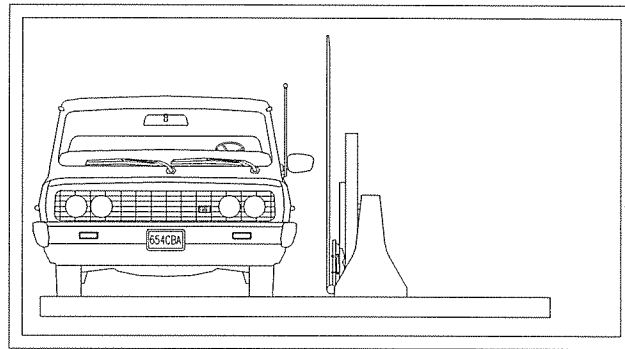


Figure 5: Initial configuration of the movable barrier RSV

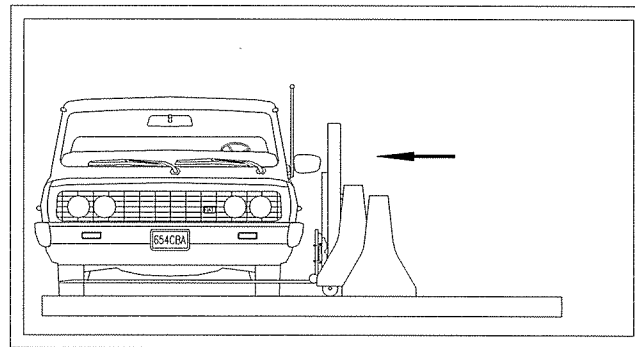


Figure 6: Wheel deployment and approach to incident

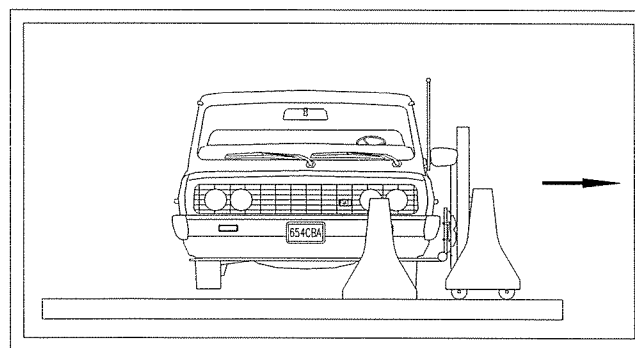


Figure 7: Clearing the roadway incident

Over Barrier Lift System RSV (OBLS RSV)

Since the AHS roadway is envisioned to be constructed in the same way as today's carpool and bus lanes, it may be possible for the RSV's to approach the incident from an access lane or from an adjacent lane. Most likely, these lanes will be separated by a barrier of some sort (i.e., jersey barrier). The OBLS RSV would be able to lift the entire vehicle over the barrier and onto the tow vehicle. The OBLS RSV would drive in the access or transition lanes and then pull up beside the AHS incident (figure 8). Next, the OBLS RSV deploys its lift system then lifts the disabled vehicle over the isolation barrier and carries the vehicle to the nearest designated service area. This type of boom truck tow vehicle is already in use in England for towing vehicles.

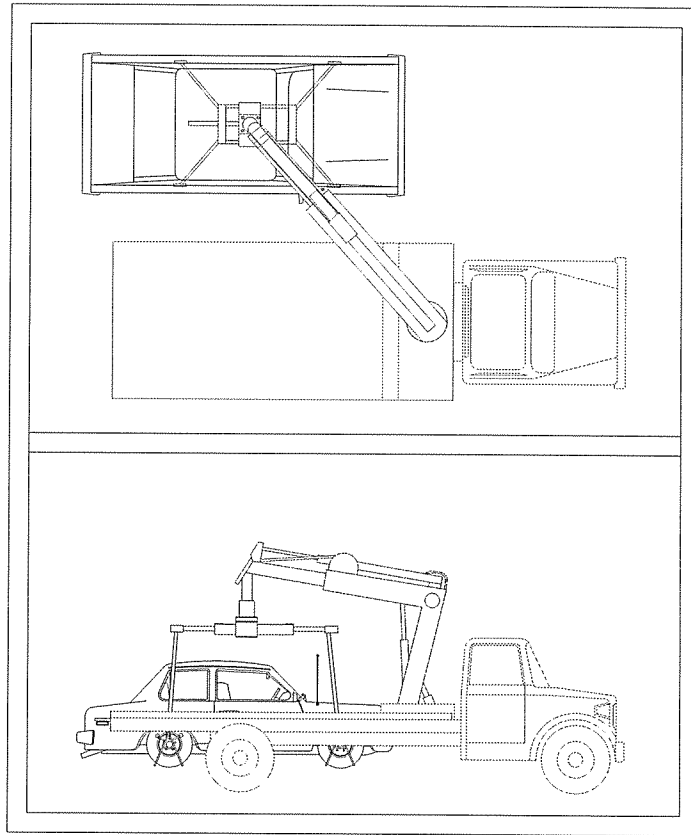


Figure 8: OBLS RSV shown lifting a vehicle.

Flatbed RSV

The flatbed roadway servicing vehicle consists of an automated flatbed servicing vehicle. Its operational scenario would be the same as described earlier with RSV bases stationed in the roadway median at specific intervals. The servicing vehicle has a small robotic grasping arm that translates along the length of the flatbed. When the arm reaches the bottom, the RSV's computer commands the arm to grasp a fixture on the underside of the disabled vehicle (figure 9 & 10). Once the vehicle is grasped, the arm translates back, pulling the disabled vehicle up the RSV's ramp. When the top is reached, the ramp lowers (figure 11 & 12) and the RSV returns with the disabled vehicle to the servicing area.

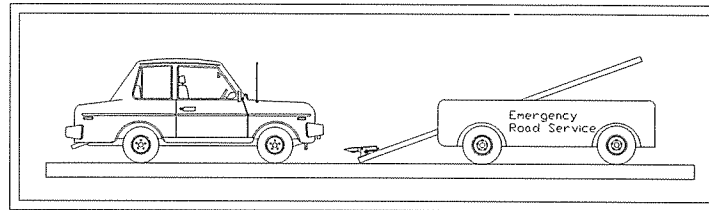


Figure 9: Initial loading configuration

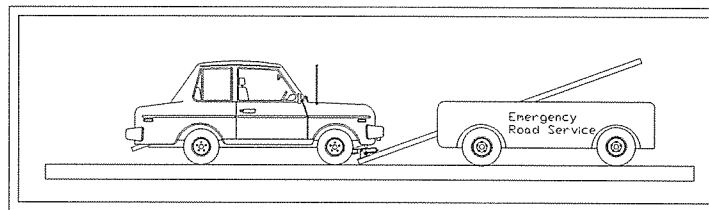


Figure 10: Initial connection configuration

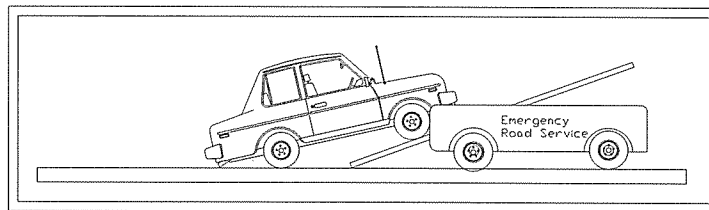


Figure 11: Vehicle being pulled up ramp

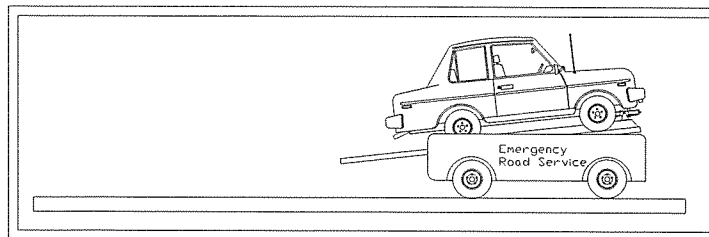


Figure 12: Final loading configuration

Barrier Mounted RSV

Since the AHS roadway lane may be separated by Jersey-type barrier, uninterrupted access to the AHS roadway may be gained by using the Barrier Mounted RSV (BM RSV). The BM RSV is designed to ride on top of the Jersey barrier to the AHS roadway incident. Once it arrives at the site, a storable arm is deployed (figure 13 & 14). At the end of the arm, a grasping fixture would then attach to a mating fixture on the underside of the disabled vehicle. The grasping arm shown here is a complete towing system with a dolly. The BM RSV would then pull the disabled vehicle at reduced speed to the nearest service area.

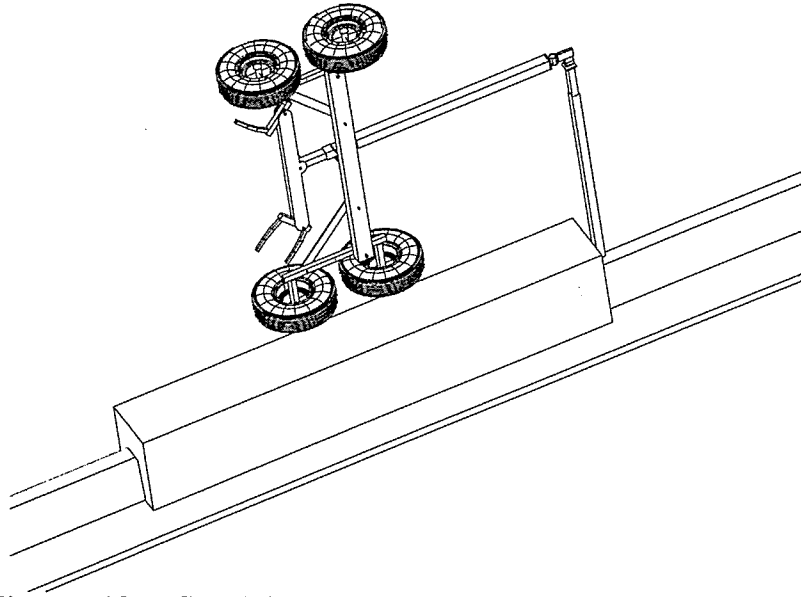


Figure 13: Servicing Dolly shown in traveling position

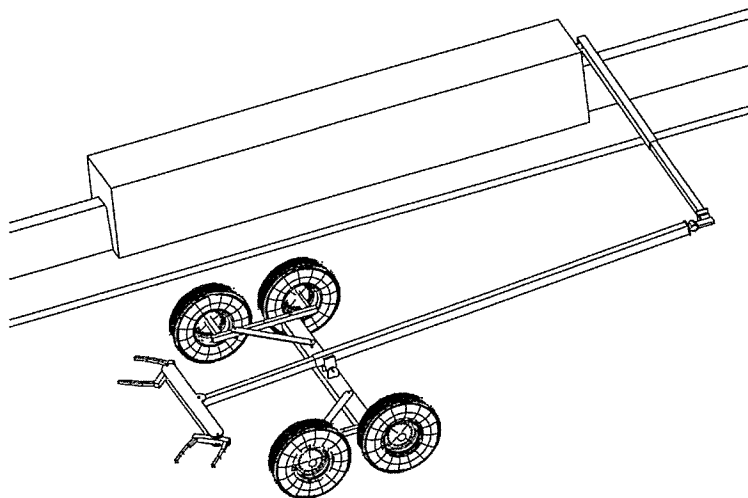


Figure 14: Servicing Dolly shown in towing position.

Movable Barrier with Manual Tow Truck

This design concept blends features from the Manual RSV and the Movable Barrier RSV. In this concept, the Manual RSV pulls alongside the incident in an access lane (figure 15). The Lift Truck attaches a power source to the barrier next to the disabled vehicle. The power source actuates the wheels contained in the barrier (figure 16a). The wheels allow the barrier to be easily moved, thus gaining direct access to the vehicle (figure 16b). The Lift Truck positions itself to deploy its lifting system, lifts the vehicle from the AHS lane and tows it into the access lane. The barrier is then replaced and the two vehicles go on to the nearest service area (figure 16c).

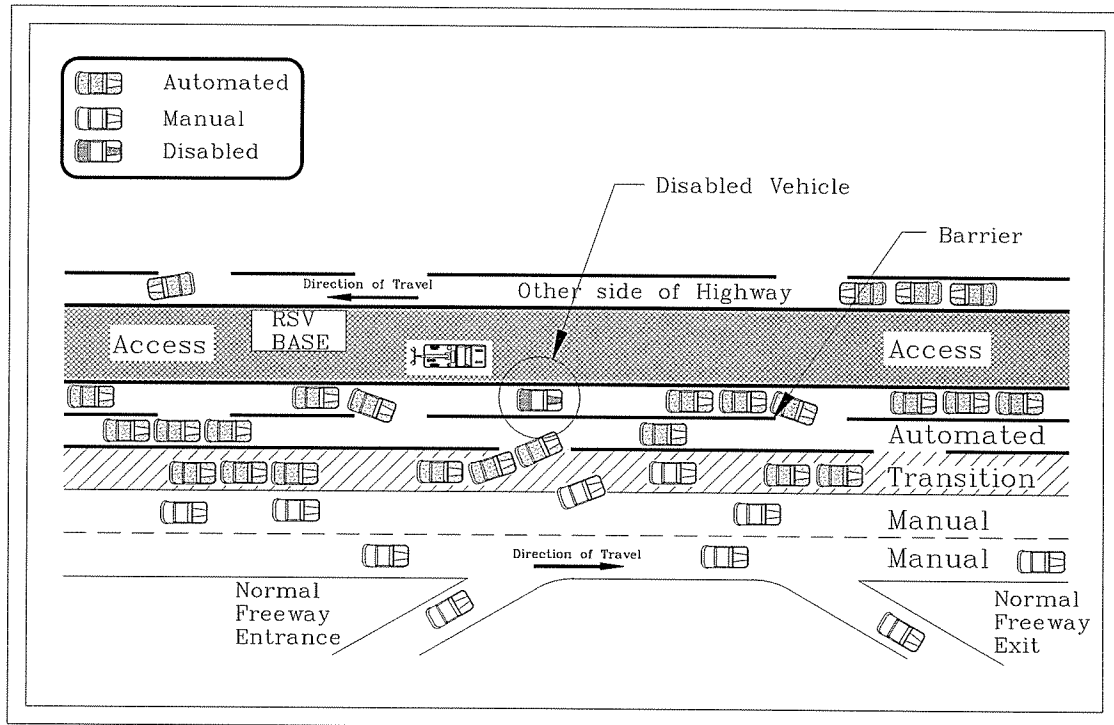


Figure 15: Typical AHS roadway with a disabled vehicle.

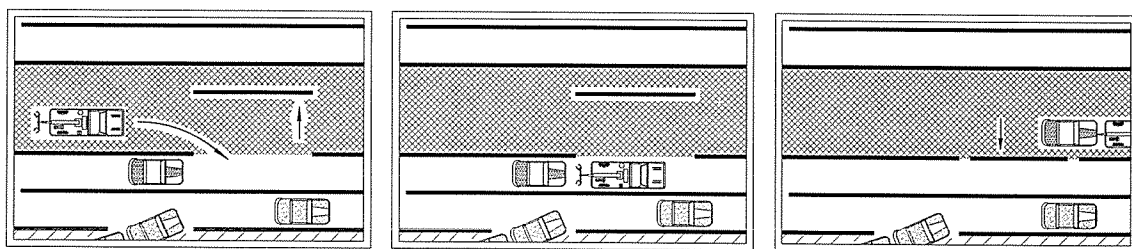


Figure 16(a,b,c): Typical steps in servicing operation.

5 Analysis

The concepts developed above assume a specific roadway configuration and are based on information available today about likely AHS'. Each of the design concepts discussed above has its own merits and situations under which it would be optimal. The six concepts are:

1. Manual RSV
2. Movable Barrier RSV
3. Over Barrier Boom System RSV
4. Flatbed RSV
5. Barrier Mounted RSV
6. Movable Barrier with Manual Tow RSV

Each of these concept's major features are summarized in table 1. The major features discussed are: whether or not an operator would be required, would the RSV require AHS equipment, how the roadway incident would be located, whether or not alterations to the vehicle would be necessary, and whether or not the technology necessary is already available.

Table 1: Features of each RSV concept.

Method of Incident Removal	Operator Required	Is RSV AHS Equipped	Method of Incident Location	Modification to Vehicle Necessary	Technology Available Today
Manual	Yes	No	Manual	None	Yes
Movable Barrier	Yes	No	Manual	Minor	No
Over-Barrier	Yes	No	Manual	None	Yes
Flatbed	No	Yes	Automatic	Minor	No
Barrier Mounted	No	Yes	Automatic	None	No
Movable Barrier w Manual	Yes	No	Manual	None	No

This paper does not address the economic implications of each of these concepts. However, future studies could include the cost analysis of each concept including more in-depth analysis of each concept. In addition, the above concepts may not be an exhaustive list of possible servicing vehicles.

6 Appendix

Moveable K-Rail Barrier concepts

Introduction:

CalTrans use of K-Rail barriers

K-Rail barriers are typically used for separating moving traffic from work sites on and around roadways. These barriers must be able to withstand large impact loads and not move appreciably^(4,5,6,7). Since the major use is to provide work site safety, the barriers don't stay in any one place for very long. A typical barrier might be used on a site for three months then taken to its next location where it might stay another six months. During all of these moves, a crane or forklift truck must be present to lift the barrier off the truck and then to position the barriers in exact positions. These cranes and forklifts are very expensive and can quickly drive up the costs of a construction operation. This is where the Moveable K-Rail Barrier can be used.

AHS application overview

In an Automated Highway System (AHS), there will be a need for removing disabled vehicles from the roadway. The response time of this removal operation will be critical to smooth AHS traffic flow. In the attached report, the concept of a Moveable K-Rail barrier servicing vehicle is presented. The basic idea uses a K-Rail barrier that has the ability to be moved. This barrier has a lifting mechanism attached to it that can lift a disabled vehicle. Once the disabled vehicle is lifted, the barrier would be moved thereby removing the disabled vehicle from the roadway.

General costs overview

The standard K-Rail barrier used by CalTrans varies in cost depending on the style of barrier and the location of the barrier manufacturer. The cost benefit of a moveable barrier would have to be weighed against the cost of having a crane and equipment on a construction site for additional hours as well as the wages of crane operators and additional employees.

Specifications for CalTrans K-Rail barriers

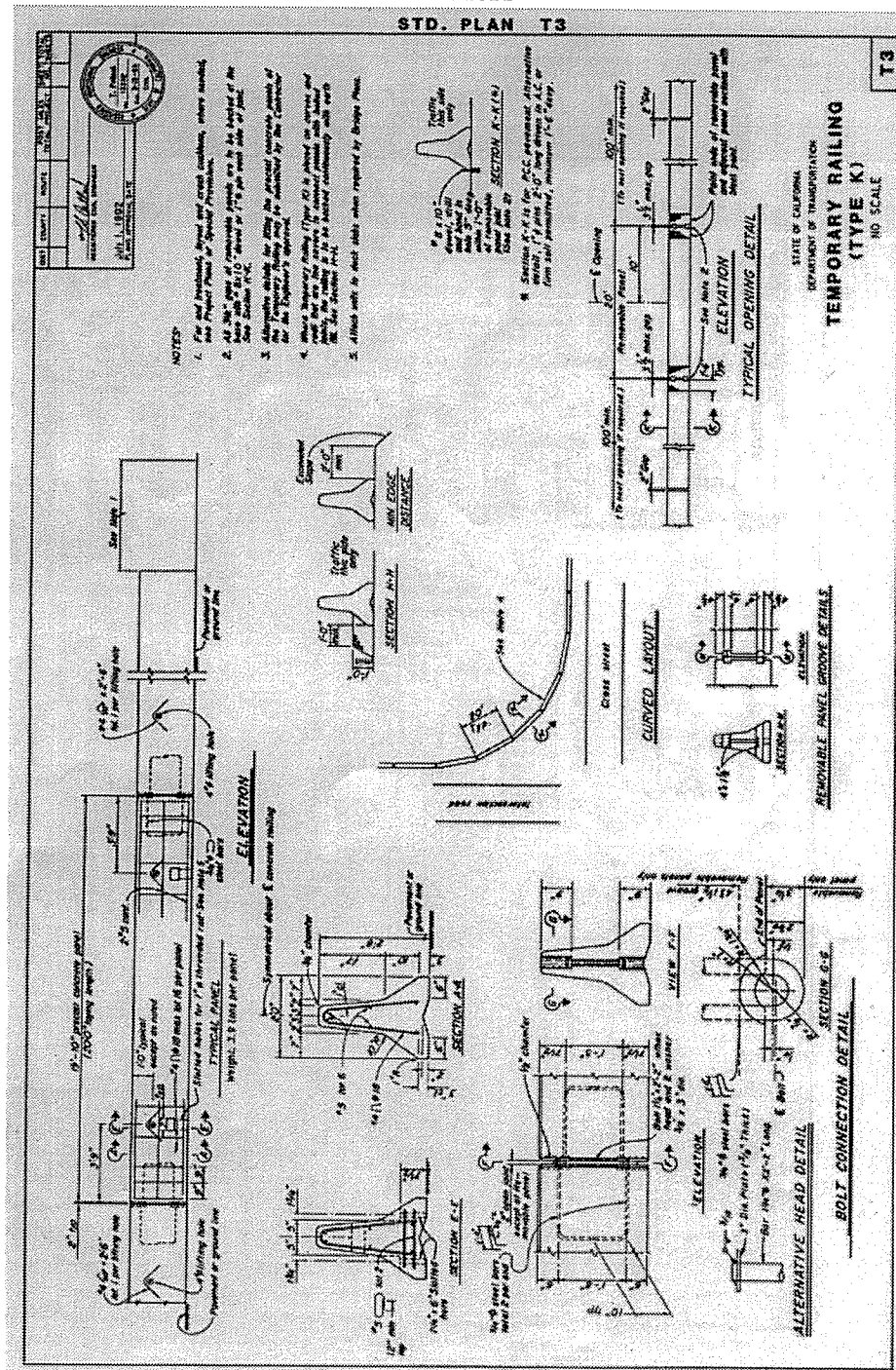


Figure 17: Dimensions, Placement, and Orientation of K-Rail barriers

Initial concepts for Moveable K-Rail barriers

Designs for the Moveable K-Rail barrier

As discussed earlier, the K-Rail barrier must be moved in an efficient manner from site to site. The method of placement discussed here should save many hours of labor by eliminating the need for a forklift truck or crane for final placement.

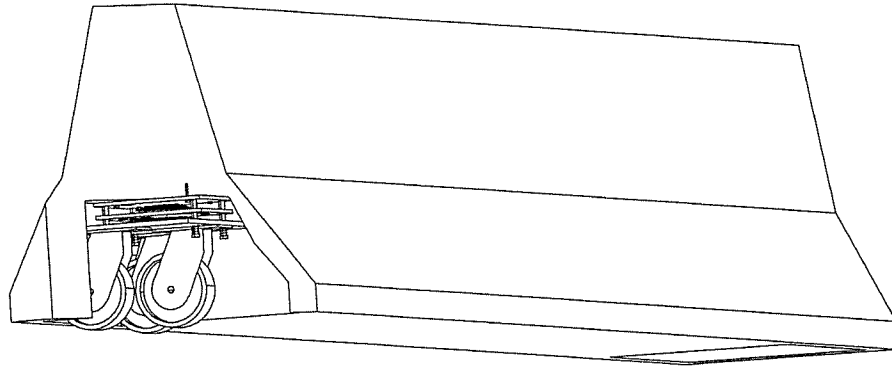


Figure 18: Moveable barrier concept with casters shown.

Mat-jack lift description

The first method of placement discussed here uses wheels and air operated jacks that are completely enclosed in the barrier. This lift concept lifts the barrier by forcing the wheels down relative to the barrier (see figure 19). This force is created by placing an inflatable pillow jack between two plates that are restrained to move in only the vertical direction. The wheels are attached to the lower plate.

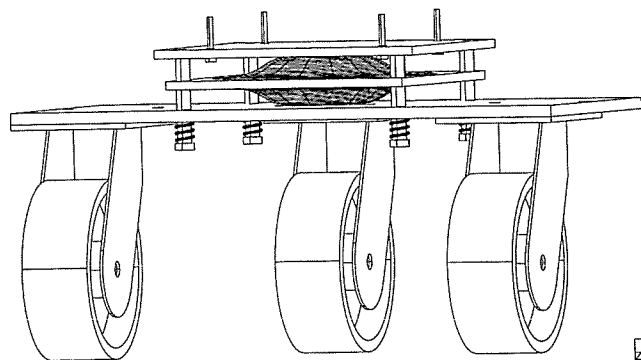


Figure 19: Front view of lift mechanism.

Once the barrier is lifted, it can be pushed manually into place or for short distances around the work site. In order to minimize the effects that small pits and debris on the ground would have on the movement of the barrier, the use of large diameter wheels with soft exterior, i.e. 8" polypropylene, should be used. The air operated jack studied is capable of lifting 12000 lb.

(54 kN) which is more than enough lifting capacity for the barriers studied⁽³⁾. The barrier would have one set of wheels and a jack at each end. This would allow the operator to lift one or both ends of the barrier as he or she saw fit to align the barrier easily. The jacks should operate off standard compressor air available on a construction site or vehicle compressor (90 - 100 psi.).

Air bearing lift description

This concept involves using forced air to lift (or hover) the barrier. Once the barrier is lifted, it could be manually pushed with relatively small forces.

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