California AHMCT Research Center
University of California at Davis
California Department of Transportation

DEPLOYMENT SUPPORT OF AHMCT MACHINES 1999-2002

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AHMCT Research Report
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16. Abstract

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The scope of deployment support work included working with Caltrans maintenance and equipment operators for field testing of the various equipment developed at AHMCT and serving as a liaison to AHMCT engineering staff thus expediting the development and commercialization process. This involved travel to test sites, operation of deployed machines, field repair and developing reverse engineering solutions, testing of machine and evaluation of test results, and engineering improvement suggestions.
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Deployment Support

Abstract

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Deployment Support

Executive Summary

The AHMCT Research Center has been developing and field testing demonstrable prototypes for many years including machines to paint aerial survey marks, apply herbicide selectively to actively growing vegetation, remove litter and debris from the roadside, etc. The AHMCT Research Center has been involved with Caltrans staff in initial prototype testing. Test results have typically indicated which aspects of the prototypes need to be re-engineered for second generation integrated prototypes and ultimate commercialization. In order to complete a thorough testing and evaluation period, extensive field support is often needed.

The support of machines during the field testing and evaluation period is a critical part of the machine development process. Being first generation integrated prototype machines, they are rarely totally "turn-key" and typically require additional adjustments in the field. Depolyment Support has provided a means to follow through with the field testing without drawing heavily on the AHMCT research engineering staff, who are involved with other ongoing projects.

Generally, Deployment Support works with Caltrans operational personnel in the field providing on-site training in machine operation and safety. Additionaly, information is gathered regarding the effectiveness and robustness of the machine design. Machine repair is typically conducted in the field; however, larger modifications are occasionally completed at the AHMCT facility. In addition to providing field support, information gathered during field testing is often provided to the AHMCT research engineering staff to facilitate the development of new machines.

Deployment Support has worked closely with Caltrans to coordinate the field testing and evaluation efforts of the various projects. It is the goal of Deployment Support that these coordinated efforts between the AHMCT Research Center and Caltrans will continue to grow, enhancing the relationship and technology of projects developed by Caltrans and the AHMCT Research Center.

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Disclaimer / Disclosure

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Program, within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the New Technology and Research Program of the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities.

The contents of this report reflect the view of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the STATE OF CALIFORNIA, the FEDERAL HIGHWAY ADMINISTRATION or the UNIVERSITY OF CALIFORNIA. This report does not constitute a standard, specification, or regulation.

Deployment Support

Chapter1
Introduction

The Deployment Support Task Order has allowed for a wide range of support to numerous AHMCT projects from July 01, 1999 to June 30, 2002. The primary goal has been to provide field support for all AHMCT projects undergoing field-testing and evaluation. In addition to training operators in safe machine operation, field support has included reverse engineering and design modification work. On several projects, close coordination with the Caltrans Equipment Headquarters staff has facilitated the cooperative effort of development and assembly. The primary projects this task order has been involved with are the Intelligent Herbicide Applicator Sprayer (IHAS), Debris Removal Vehicle (DRV), Advanced Snow Plow (ASP) and Roadview Systems, Automated Cone Machine (ACM), Automated Roadway Debris Vacuum (ARDVAC), and the Longitudinal Crack Sealing Machine (LCSM).

Field testing and reverse engineering is a key component in the development of a robust and optimal machine. Once a machine is engaged in actual field testing, unexpected problems often arise. Deployment support has provided a means for identifying needed improvements and by consulting with the engineering staff, implementing optimum changes to increase the robustness of the machines.

Chapter 2
Supported Projects

2.1 Introduction

The support of machines is extensive during the field deployment phase of the project. However, additional support is provided during the development phase. Information gathered during the field testing is often important during development of other projects. Current highway maintenance equipment, practices, and operator interface issues are a few items of great value.

2.2 Intelligent Herbicide Applicator Sprayer IHAS

During the first year of this task order, Caltrans maintenance headquarters had shown interest in continuing testing with the IHAS system, however, the vehicle was not running at the time. A new 12V – 120V power inverter was installed and repair work to the main computer completed. Using water in the main spray tank, the system was initialized and tested at the AHMCT facility and at several equipment demonstrations including the CAATS show at Cal Expo. The machine was run in several different environments and failures, reported during previous testing, were recreated. In an effort to improve the machine, information about the current herbicide operation was gathered. Prior to the implementation of any changes in the machine, a new smart herbicide spraying project was initiated requiring the use of the IHAS platform.

2.3 Debris Removal Vehicle (DRV)

The current Debris Removal Vehicle (DRV) was originally manufactured by Pic-All Inc. After being in the field for several years with little operational time, the Caltrans Equipment Service Center and the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) decided to pull the machine out of the field and entered into a cooperative effort to repair the DRV. The machine was taken to the AHMCT Research Center, in February of 1999, where it was tested and analyzed and later taken to the Caltrans Equipment Service Center. The project scope was defined collectively by the AHMCT Research Center and Caltrans at a meeting attended by persons listed in attachment (Appendix A).

Project Scope

- Evaluate the existing mechanical, hydraulic, and electronic control structure
- Devise a plan of action to repair the existing machine with the goal of re-deployment for the purposes of field operational testing and evaluation

Even though a majority of all parties involved agreed that a complete redesign and rebuild would have been ideal, it was determined that a limited rebuild was the most timely solution to implement in order to evaluate the interface of a machine with an actual roadway for the purpose of retrieving debris. The following plan of action was devised.

<u>Plan of Action</u>

- Install and implement a new hydraulic and electronic control system that exhibits reliable and controllable motion
- Make reasonable structural repairs to the azimuth joint and short arm sections
- Perform the repair with a goal of one year of usable service for the purpose of evaluating the machine concept

Work on the rebuild of the DRV was conducted at the AHMCT Research Center and the Caltrans Equipment Service Center. Upon completion of work on the DRV, demonstrations were given at both the AHMCT Research Center and the Caltrans Equipment Service Center to gain approval for release for field operational testing and evaluation (Appendix A). Approval was obtained for release on July 31, 2000. In addition, AHMCT prepared a complete DRV manual titled, "The Debris Removal Vehicle Operator's Manual and Technical Reference" (Appendix B).

The DRV underwent service for the first 1 and ½ months after being delivered to Caltrans District 8 in San Bernardino. There were several problems with the truck equipment including the engine brake, fuel sensor, side mirror, and hydraulic hoses. Once the repairs were completed in mid-September, 2000, the DRV began the field operational testing and evaluation phase.

Technical support has been provided throughout the DRV's field testing in order to successfully evaluate the machine in a real world environment. In addition, observation of the machine in use has provided an insight into the interaction between the machine and the roadway and the operator and machine. An evaluation report (Appendix A) was generated for the DRV which discusses the aforementioned interactions in detail along with observations about the debris removal process. Included in Appendix A is a summary of the repairs conducted on the DRV.

2.4 <u>Winter Maintenance Machines</u>

The ASP and Roadview projects have snow plows being field tested in District 2 (Burney) and in District 3 (Kingvale). Support for the plows has been provided in the field, at the AHMCT facility, and in Flagstaff Arizona. The projects have been successful and there is significant interest in continuing the testing in these areas. The operators are enthused with the Roadview interface and have been encouraged with the improvements implemented over the last few years.

Testing of the snow plows in the three different regions has provided a valuable diversification in environments to continue research. The Kingvale test section is a wide section of freeway with several lanes of traffic traveling in the same direction. While Burney is a two-lane bidirectional highway with closer roadside hazards such as trees. The section in Burney and in Flagstaff has provided an ideal environment to further develop the anti-collision radar system. When traveling around corners, trees can appear as a possible collision; however, these are merely false warnings. Hence a false warning suppression algorithm was developed and tested, in these areas, to eliminate false warnings being indicated to operators.

2.5 Longitudinal Crack Sealing Machine (LCSM)

The Caltrans Equipment Service Center pulled the AHMCT Longitudinal Crack Sealing Machine (LCSM) out of the field and assigned their Deployment and Development Group the task of making alterations including the addition of a second crack sealant melter. Support was provided during the development to explain mechanical design considerations, electronic circuitry, and develop new control software to meet there needs. During the initial startup and testing, it was determined that more flexibility was needed to facilitate the system tuning. Additional software was developed to allow the operator to monitor, via a digital display, which melter is active, each tanks pour time, and change the tank timers from the display. The LCSM was initially deployed to District 11 and is currently being used in District 6.

Additional work associated with the LCSM included providing training, to the primary LCSM technician, in PLC logic theory, and troubleshooting automated process with software, via a laptop interface. Software was backed up and provided along with instruction on the use of the operator interface (Appendix C).

2.6 Automated Cone Machine (ACM)

The ACM has undergone a variety of field tests resulting in several changes in hardware. The machine has been tested by Caltrans personnel and a private contractor, Granite Rock Construction Company. Testing has included usage on busy high speed highways and on inner city narrower roadways. In addition, extensive testing has been conducted at the AHMCT facilities test road. Operators have been able to quickly adapt to the operation of the machine and have all found it easy to use.

Originally the ACM used an opto-sensor on the drive shaft to sense vehicle displacement. Testing revealed that the opto-sensor’s signal was unreliable at a vehicle speed over 10 mph. In addition, debris would often coat the sensor rendering it ineffective. Therefore, modifications were made to use the vehicles OEM vehicle speed sensor (vss) to interface with the embedded controller to measure vehicle displacement. Testing resulted in a reliable signal in excess of 20 mph, which is effectively the maximum speed that cones can be placed.

While testing the ACM in the central valley, a problem with low battery voltage was detected. The problem was determined to be with an excessive electrical loading. Running the ACM equipment, air conditioning, sign board, headlights, and electric powered fans for the engine cooling exceeded the capacity of the existing electrical system. However, the duty cycle of the excessive loading was fairly short. It was determined that adding electrical storage capacity would be the optimal improvement.

Therefore, a battery charging isolation system was added including two additional heavy density batteries. The additional batteries allowed more energy to be stored, while driving to and from the work zone, and used during the short time use of the ACM equipment. The system was tested repeatedly and found to be a sound solution.

The cone stowage assembly on the ACM was an area that required frequent inspection and maintenance. Due to the increased interest in extended field testing, it was decided to modify the design to increase the robustness of the assembly. There were two components on the stowage assembly that required high maintenance, the v-track rollers and the main radial-load flat track rollers. The flat track rollers were simply undersized for the mechanical loading encountered and would be replaced with a larger one. Therefore, a new gripper assembly had to be built to accommodate a larger roller. The v-track rollers were splitting due to higher than expected torsional loading on the gripper assembly. The addition of a third track providing support on the top of an existing flat track roller greatly reduced the torsional loading on the v-track rollers. The two improvements to the gripper assembly have improved the robustness of the stowage assembly and greatly reduced the required maintenance.

Prior to continuing field testing, new cones were ordered, according to the latest Caltrans specification, and installed on the machine. However prior to installation, the rubber feet on the cones had to be removed, as required by the current ACM design. The new cones were more pliable than the previous cone. The pliability affected several parts of the cone placement and retrieval process; however, the detection and grabbing of the cone in the secondary funnel area was problematic. The upper portion of the cone periodically collapses, sliding under the secondary funnel, allowing the base of the cone to get trapped behind the flag of a limit switch. This configuration prohibits the cone from being detected or retrieved. Therefore, new flag geometry was developed that eliminated the possibility of a cone being trapped and undetected. The new design was tested and worked effectively.

Testing in Santa Cruz on highway 1 with Granite Rock Construction Company was an excellent opportunity to observe the interaction of the ACM with congested traffic. The distraction to drivers of having an interesting automated machine operating next to them and the physical obstruction of the ACM drop box were two areas of concern to investigate. It was found that neither of the concerns were problematic. Most drivers never even noticed that the ACM was working autonomously. In addition, the protruding drop box did not appear to be problematic.

Caltrans conducted further testing of the ACM in the Livermore and San Jose areas. On the freeways the machine also performed great. The only real concern was the spacing accuracy of the cones. This is a known problem and is limited by the physical speed at which the ACM components can operate and the speed of the vehicle. With a little practice the operators were able to speed up or slow down their driving to get a more desired spacing.

With each field test, complete training in the safe operation of the machine was provided. Additionally, operators and their supervisors were provided a copy of the Automated Cone Machine Safe Operation documentation (Appendix D). Training continued on an as needed basis during field testing. Technical support was a priority in order to facilitate a successful testing period.

Caltrans' interest in the ACM has grown strong; therefore, they have decided to acquire the machine from the AHMCT Center. Field support will be provided by AHMCT Deployment Support to facilitate Caltrans' evaluation of the machine. Extensive training was also provided for the Caltrans representative assigned to the machine. A transfer document was prepared and is included (Appendix E) in this report.

2.7 Automated Roadway Debris Vacuum (ARDVAC)

As a result of the effort to commercialize the ARDVAC, a field test and evaluation phase was not feasible. However, testing was conducted and supported along the AHMCT test road. The support included the design of an analog control interface, contributing information regarding current debris removal needs and removal processes, operation of the machine, and assisting in the evaluation.

Initial testing was conducted along the AHMCT test road in order to observe the nozzle motion and debris removing capability. A variety of debris was spread along the roadway and then retrieved using the ARDVAC. Video footage of the testing was taken along with still photographs.

2.8 Summary

Deployment support has provided a means to integrate prototype machines into the workplace. Over the course of each supported project, reverse engineering changes have been implemented to increase the robustness of the machines and serve as information for future design considerations. In addition, valuable feedback from operators and field supervisors has been gathered.

The primary work has involved preparing safe machine operation manuals and conducting field training for the assigned crews. Furthermore, field support is provided to address any machine failures or problematic operations. Repairs and modifications are generally conducted in the field as soon as reasonably possible. Occasionally, more involved modifications are conducted at the AHMCT facility and scheduled in between field assignments.

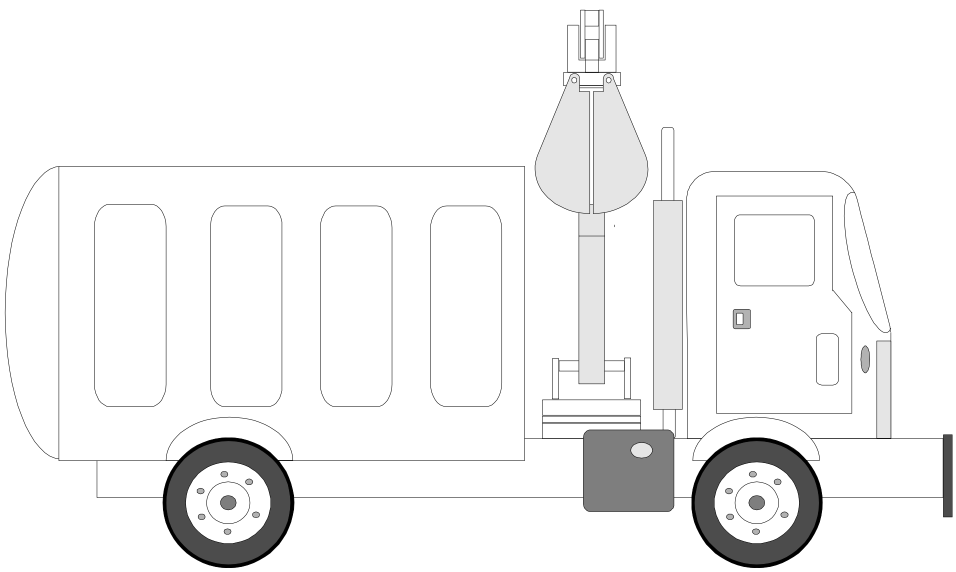
Throughout the course of this contract, deployment support has worked closely with Caltrans on several projects. The coordinated efforts of the AHMCT Center and the Caltrans Equipment Service Center and Maintenance division will continue to grow, enhancing the relationship and technology of projects developed by Caltrans and the AHMCT Research Center.

Appendix A

Debris Removal Vehicle (DRV)
AHMCT Evaluation Report

Aaron Raley
Deployment Support

October, 2001



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Introduction

The field operational testing and evaluation phase of the Debris Removal Vehicle (DRV) project has produced valuable feedback regarding the interface of the operator with the machine and the machine with the environment. Equally important is the infrastructure in place and its role in the removal of roadside debris. The information gathered should facilitate the formulation of efficient solutions to the remaining problems.

This report addresses the interface of the machine with the operators and the roadway for the purpose of retrieving debris. It includes observations of mechanical, control, and ergonomic engineering issues. Observations and feedback were gathered on location by the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) during the field operational testing and evaluation phase.

Background

Debris is usually retrieved in a two step process. A crew is initially deployed to gather the debris. Loose debris is placed in bags and stacked on the roadside along with trimmed vegetation, tumbleweed and other larger debris such as lumber, tires and mufflers. The next step is to remove the gathered debris from the roadside. Previous methods relied on a crew to drive down the road, exit the vehicle, and manually throw the debris into a truck. They then either walk down the roadway to the next pile or drive further down the road. The DRV was developed to provide a safer solution to the removal of the debris.

The current Debris Removal Vehicle (DRV) was originally manufactured by Pic-All Inc. After being in the field for several years with little operational time, the Caltrans Equipment Service Center and the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) decided to pull the machine out of the field and entered into a cooperative effort to repair the DRV. The machine was taken to the AHMCT Research Center, in February of 1999, where it was tested and analyzed and later taken to the Caltrans Equipment Service Center. The project scope was defined collectively by the AHMCT Research Center and Caltrans at a meeting attended by persons listed in attachment (refer to attachment B).

Project Scope

- Evaluate the existing mechanical, hydraulic, and electronic control structure.
- Devise a plan of action to repair the existing machine with the goal of re-deployment for the purposes of field operational testing and evaluation.

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- Install and implement a new hydraulic and electronic control system that exhibits reliable and controllable motion.
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Work on the rebuild of the DRV was conducted at the AHMCT Research Center and the Caltrans Equipment Service Center. Upon completion of work on the DRV, demonstrations were given at both the AHMCT Research Center and the Caltrans Equipment Service Center to gain approval for release for field operational testing and evaluation (see attachment A). Approval was obtained for release on July 31, 2000.

The DRV underwent service for the first 1.5 months after being delivered to Caltrans District 8 in San Bernardino. There were several problems with the truck equipment including the engine brake, fuel sensor, side mirror, and hydraulic hoses. Once the repairs were completed in mid September, 2000, the DRV began the field operational testing and evaluation phase.

Description of Machine and Operation

The Caltrans/AHMCT Debris Removal Vehicle (DRV) is an operator controlled garbage collecting manipulator with limited automatic modes to assist in the most tedious tasks. The DRV consists of a dual steering Volvo-White truck equipped with a 10 yard garbage bin and a robotic arm consisting of an open kinematic chain of six revolute joints. The operations are controlled by a joystick and switches mounted on an operator control console. In normal operation, the operator programs preset manipulator locations into the machine. These preset locations are activated by the joystick pushbuttons. In the field, the operator deploys the manipulator to a preset location by depressing the appropriate button. Then, the joystick is used for fine adjustment of the manipulator in order to grab the debris. The bucket is then closed. When the operator is satisfied that the payload is secure, the automatic dump action is initiated with a specific button combination. The manipulator repositions itself over the compactor entryway, releases the garbage, and repositions itself again to be ready for the next task. The operator can then reposition the vehicle and restart the collection process again. If the operator determines that the garbage in the body needs to be compacted, the entire compaction cycle is initiated by another button combination from the joystick.

Evaluation of User Interface

The design of the operator's control interface had to address a wide range of considerations. The machine is designed to be operated from either side of the cab and performs tasks on either side of the machine. In addition, the workspace of the arm must be versatile requiring the operator to be able to view a large area. This is difficult for an operator constrained in a standard vehicle cab and presents ergonomic design issues. Important areas to investigate are the interface of the operator with the controls and the interface of the operator with the task.

The relation of a joystick axis to its associated joint and joystick motion to joint directional motion is very intuitive. An equipment operator can accomplish the joystick operation quickly from either side of the vehicle. In addition, the automated motion commands are easy to remember and execute. The programmed automated motion sequences were precise and efficient while still allowing the operator to take control by simply moving the joystick off center and then directly controlling the arm. Due to the versatility of the joystick, the machine can nearly be operated entirely from the joystick using one hand. All operators using the machine were able to adapt to the control interface without significant effort. Some of the features, such as the changing of preset positions, required more training, however, they are not used often and therefore, they are not always committed to memory.

One area that required additional operator training was the interpretation of the indicator lights. In order to limit the number of indicator lights, their functionality was overloaded. The overloaded functionality of the lights means that a constant 'on' light indicates something entirely different than a blinking light. Adding to the complexity was the labeling of the light. For example, the light labeled *Restraint Pin* indicates one of the restraint pins on the arm is still engaged; however, if the *Restraint Pin* light is blinking it indicates that when trying to perform an automated motion the controller detects a possible collision with the truck, such as the side gate not being in the down position. An operator might execute an automated motion command and then when the arm does not respond notice the *Restraint Pin* light blinking. Rather than looking to correct the possible collision, perhaps lowering a side gate, a repair order might be made indicating the machine was not responding to the command even though the restraint pins were disengaged. The solution is either additional indicator lights or clearer labeling distinguishing the significance of the constant on light and the blinking light. Alternative solutions could incorporate either a text based display such as a LCD or voice recorded message to describe the current state of the machine.

One of the most important concerns is how comfortable the operator is running the machine and how much effort they have to put forth. The universal complaint by the operators involved was the uncomfortable orientation of the operator to the task. The seats in the vehicle are in a fixed position facing forward; however, the task is on the side of the vehicle and often requires the operator to turn their head greater than ninety degrees. This requires that the operator work while looking over their shoulder. Working in this configuration promotes neck and back pain. One solution would be to utilize a cab that would accommodate seats that rotate and lock in place at ninety degrees. This would allow the operator to drive the vehicle then adjust the seat in order to face their task, similar to the operation of a backhoe. Another solution would be to have a vehicle that utilizes a driver and an operator. The operator seat could be left in the direction facing the task while a dedicated driver managed traffic. In addition to the orientation of the driver, the type of control interface is important. There were no reported complaints by any operators regarding the use of a joystick relating to comfort or effort.

The efficiency of the DRV is related to the experience of the operator and its integration into the debris removal program plan. The more frequently that an operator used the machine the more efficient the operation became. There were several techniques operators employed as their exposure to the machine increased that sped up the operation. If bags are not stacked closely together, it is often more efficient to grab several bags with the machine and then placing them on an adjacent pile, retrieve the full load of garbage. The cycle time for dumping garbage requires as much debris to be gathered as reasonably possible to make the process efficient. In addition, the operator can drive from one pile to another while the machine is completing the dump cycle. The speed of the arm was limited by its structural integrity not the hydraulic power or flow restrictions. Since the existing arm was used, the performance of the system was detuned to avoid accelerations that could exceed the limitations of the arm. A better designed arm would allow for increases in the speed of the operation. As important as operator experience is the execution of the program plan. The workspace of the DRV must be considered when debris is gathered and bags are piled up. If the operator has to exit the vehicle to move debris within the workspace then the purpose and efficiency of the process is greatly reduced. In addition, the debris should be piled such that a maximum payload is obtained without repositioning the manipulator or executing an inefficient dump cycle. Crews gathering the debris have to be aware of the machinery being used to remove the debris from the roadside.

Evaluation of Machine Design

The DRV is a versatile machine that allows an operator to retrieve a wide range of debris in many different environments. By the nature of a prototype machine, many complications are not conceived until adequate field testing is completed. Two areas of complications were the type of debris encountered and the diverse terrain.

The robotic arm on the DRV is designed to retrieve the garbage from a large workspace and then dump it into the compactor body. In order to allow the machine to dump garbage automatically without feedback of its surroundings, many assumptions must be made when scheduling the sequence of motion. The control sequence that was implemented works great for the majority of the work; however, there are two cases where complications arise. Working on a bank creates a problem for the automated dumping sequence and the preset motion sequence. Preset positions have to be set to stop the manipulator higher, relative to the roadway, on banks in order to prevent the manipulator from driving into the ground. The programming of the presets can be accomplished quickly by the operator with simple commands entered from the joystick. The automated dump sequence is hard coded in the controller and requires more effort. Simply, changing presets is a software feature where changing the dump sequence is an algorithm consideration. The problem with the automated dump command on banks is related to the sequence of events and that the arm starts at a much higher position. Adding more software features could eliminate this complexity. The second problem arises when the work zone is close to the vehicle as found when retrieving debris next to a sound wall or on a narrow shoulder. In both of these cases the garbage can be dumped but it takes more tedious manipulation of the arm by the operator, hence, decreasing the efficiency of the machine. With further investigation, modes could be implemented where different code sections are executed based on the environment selected by an operator. The ideal solution may not be just a programming modification, but rather a conceptual change in how garbage is dumped once retrieved and the design of the arm.

The type of debris encountered can be better defined now that testing has occurred. The type of debris directly affects two areas of the design, the clam shell and the weight capacity. The design of the clamshell works geometrically for the majority of debris. The few exceptions are loose objects that can fall out of the clamshell, such as a soda can or other small objects that were not placed in bags, and objects that are two long such as lumber. Lumber either slips from the grip of the clamshell or jams it open making it difficult to dump. Tumbleweed was also retrieved using the DRV. The complication with tumbleweed was keeping it in one place. Stacked in piles it is easily blown away or disrupted when encountered by the clam shell. Although the DRV was successful at retrieving the tumbleweed fairly efficiently, a vacuum type machine would be better adapted. With the exception of the tumbleweed, these items are a small percentage of the debris retrieved but are reasonable to consider in the design of the end effector. The heaviest items encountered were bags of ice plant. It is possible to exceed the lifting capacity of the DRV's arm with a full load of ice plant in certain geometric configurations of the arm. Changes to the kinematics of the arm would have been reasonable at the time of the rebuild, however, a new design would be prudent. The lifting capacity of the arm was sufficient for the remainder of the debris encountered during testing.

Evaluation of Machine Effectiveness

The efficiency of a machine is hard to determine without a controlled experiment. Data was gathered regarding how many bags of garbage the DRV retrieved in a given trip, but it does not state if there were more bags available to be picked up or not or the amount of time it took. It does not state how distributed the debris was or if the debris was stacked properly for the DRV to work as designed. In addition, it must be established whether the number of bags, the volume, or the weight of the debris retrieved is of importance in measuring the DRV's effectiveness. The operation of removing debris using the DRV is a single person operation. Arguments are made that current operations only use one person also, however, probate workers are not counted yet do reflect a safety risk. Therefore, the statistics can be listed but comparisons should be made cautiously.

Records of the DRV's usage have been kept but with limited information. The number of bags retrieved display an uneven distribution. It appears that many times all the bags available were picked up and report an average of 150 bags in a trip. Other data shows that 350 bags in a trip were retrieved, implying that more bags were available and maybe placed in a convenient manner. Data regarding how long it took in the shift to retrieve the debris has not been recorded to date. Observation indicates that if the debris is handled with anticipation of the DRV being used to retrieve it, that the machine could be more efficient than a manual operation and considerably safer. Obviously, improvements in the design of the machine would greatly increase the efficiency providing for a debris removal process more efficient and safer than the current operation.

Key Points

- Debris removal plan must be in place and complete. The plan should describe the areas and type of debris targeted for each piece of equipment. The resources needed to support the method, and the techniques to be used.
- The operator should be in a comfortable position while performing assigned task.
- Joysticks are easy to use and preferred by operators.
- Use of indicator lights may be replaced or complimented by text on a LCD display or pre-recorded voice messages.
- Automated tasks should be quick and allow the operator to multitask.
- Software modes customized for different work spaces, such as working on banked shoulders or near sound walls.
- Versatile or interchangeable end effector.

Conclusion

The importance of the field operational testing and evaluation of the DRV is the lessons learned from observing the machine used by operators in an actual working environment. Operators must be comfortable when operating a machine and the machine should automate the tedious task. In addition, a well defined and executable debris removal plan must be in place.

The debris removal plan is as important as the machine design. The debris is first managed on the roadside before it is retrieved. Ice plant is trimmed and gathered along with tumbleweed, loose garbage is picked up and bagged, and larger debris is stacked along the roadside. Then, a secondary operation retrieves it from the roadside. However, the retrieval process in the second step has to be known during the gathering process in step one in order for the program to be efficient. In the case of using a machine to retrieve the debris, the debris must be placed in the workspace of the equipment and in an orientation that allows the machine to work at maximum efficiency. For example with the current machine, debris should be placed along the roadside within the workspace of the arm and in piles the size of the maximum payload of the clamshell. This permits minimal effort on the placement of the end effector and maximum efficiency in the dump cycle.

Providing a comfortable method for operating a machine reduces work place injuries and facilitates efficiency. The operator should be able to face the task either directly or through an electronic viewing screen. Considerations should be made at the concept stage to plan for the operator being comfortable during the operation. The current layout of the design required that the operator be able to run the machine with one hand while looking out the side window. This was accomplished with the combination joystick pushbutton control. There were no reported complaints about the ergonomics of the joystick. In fact, operators were enthused about the use of the joystick pushbutton combination.

Deploying the arm from the folded up position to the roadside is a complex process because of the pre-existing design of the arm. Likewise, folding the arm up to dump the garbage is also a tedious task. Both of these sequences were automated. Automating features allows an operator to accomplish a second task such as preparing for the next action or possibly moving the vehicle to the next location while the machine finishes a sequence. Field testing results indicate that software features could be added allowing for changes in the environment such as working on banked shoulders and working next to sound walls. In addition, an efficient method of dumping garbage and a simpler arm design should be investigated.

Looking Forward

The purpose of looking forward is not to document answers but to gather ideas for future investigation based on results of the field operational testing and evaluation phase. The development of a next generation machine should take into consideration the valuable lessons learned during this field operational testing and evaluation phase and develop a machine around the results. An operator must be comfortable and tedious task should be automated. In addition, a well defined debris removal plan has to be in place.

The operator should be able to comfortably retrieve debris working from either side of the vehicle. They should be able to view the task without looking over their shoulder or putting any other undo stress on their body. This means taking a new look at the placement and orientation of the operator in relation to the manipulator and location of the debris. Several suggestions have been made to accomplish this. The use of a center drive cab with a rotating seat and adequate viewing area through an enlarged window space addresses most of the complications encountered. This allows an operator to switch from retrieving debris off the median to the shoulder without getting out of the vehicle to change sides. In addition, the swivel and lock seat allows the operator to view the task head-on. A variation on this idea is having a cab that would accommodate swivel seats on either side using a dual steer vehicle but is less eloquent and includes redundant equipment. The idea of a camera and viewing screen has also been discussed. This would eliminate the need for rotating seats but may introduce new complications such as display brightness or seeing hazards outside the viewing area of the camera. Another arm design utilizing a linear extendable arm, such as used on extend-a-hoe backhoes, might allow the arm to reach far enough forward to make it easier to view and increase overall range.

There are many types of debris that are common to all areas. The debris consists mostly of bagged garbage, lumber, tires, and trimmed vegetation. Most of this debris can be retrieved using a common end effector, however, it is reasonable to consider different end effectors used as changeable implements. Designing with the concept of a removable implement with a standardized interface allows for the adaptation to debris localized to a single region not considered at initial development. In addition, the ideal design for 70 percent of the work should not be compromised by accommodating the other 30 percent. Payload capacity is always a concern. Field testing found that retrieving large piles of green ice plant were the heaviest task encountered in the Southern California region. It is possible that a pile of ice plant weigh on the order of 350 pounds.

A clear definition of the task space for each component of the machine must be established. To accomplish this, a clear description of the debris removal plan must exist. How versatile the arm needs to be is described by how the debris is distributed on the roadway and the degrees of freedom in the arm's workspace. If all the debris to be removed from the roadside is first stacked by a crew, then the complexity is greatly reduced. The debris can be conveniently piled in a location that requires minimal dexterity in the arm, hence eliminating the need for redundant degrees of freedom. If the arms task is only to retrieve the debris from the roadside and another component transfers it to the refuse container, then the complexity of the arm is again reduced, however, it may increase the complexity of other components on the machine. Reaching over objects such as guardrails and side of hills increases the need for complexity in the arm design and is usually only needed due to deficiencies in the debris removal plan. The workers gathering the debris were not aware of the machine being used to retrieve it and the proper way to place the debris in anticipation of its use. The ability of the arm to retrieve debris from both sides of the vehicle is a crucial design consideration. This allows the machine to work on the median and the shoulder. The key element in the success of implementing a design is the proper execution of the developed debris removal plan around which the machine was designed.

Control process needs to allow for operator multitasking. While the control software performs many multitasking operations, the ability of the operator to multitask was limited by machine design. For example, an arm could retrieve debris from the roadside and place it on a transfer component that would transfer the debris to the refuse container while either the arm returned to the roadside for another load or the vehicle was driven to the next location. In other words, while the machine is performing automated tasks the operator should be able to perform other tasks if possible.

AHMCT Advanced Highway Maintenance and Construction Technology Research Center

UCDAVIS Caltrans

AHMCT Release for Field Operational Testing and Evaluation

We, the undersigned, have observed a demonstration of the Debris Removal Vehicle and we have also visually inspected the machine. Based upon our signatures below, this machine meets our minimum standards for initial testing in actual highway operations. This machine is a first generation prototype, and accordingly, it is intended for limited operation for qualification purposes only. While meeting minimum standards, the attached report documents some limitations and critical inspection points. The machine operator should receive specific instruction on the proper use of this machine prior to its testing.

AHMCT Center:

7/31/00
Steven A. Velinsky, Director Date

7/31/00
Aaron Raley, Mechanician

PE
Phil Wong, Development Engineer

Wil White, Development Engineer 7/31/2000

7/31/2000
Ty Lasky, Development Engineer

7/31/00
Duane Bennett, Development Engineer

Caltrans Equipment Service Center:

7/31/00
Edward J. Hardiman, Sen Equip. Engr Date

7/31/00
ASSISTANT SUPERINTENDENT HQ SHOP Date

Caltrans New Technology & Research:

7/31/00
Monica Kress, Program Manager Date

7/31/00
Juan Araya, Project Manager

Caltrans Maintenance District HQ

John M. Cattier by JLN
Date

The AHMCT Research Center, in conjunction with the Caltrans Equipment Service Center, has rebuilt the Debris Removal Vehicle (DRV). The following was the scope of the project and plan of action as determined by both of the above groups.

Project Scope

- Evaluate the existing mechanical, hydraulic, and electronic control structure.
- Devise a plan of action to repair the existing project with the goal of re-deployment for the purposes of field operational testing and evaluation.

Plan of Action

- Install and implement a hydraulic and electronic control system that exhibits reliable and controllable motion.
- Make reasonable structural repairs to the azimuth joint and short arm sections.

Due to the nature of a rebuild as opposed to a redesign, several design considerations were made. Reasonable changes and repairs were implemented to limit the time involved. During the rebuild process there were several concerns that arose. The following are the known concerns and a portion of the design considerations of the project.

Design Considerations

- Due to the need for control versatility and reliability a new controller was chosen. The ZWorld controller was a cost effective solution. The existing PWM Amplifiers were tested and found to be sufficient for the parameters of this project. The existing potentiometers used for analog position feedback were not reliable or of the quality needed for this application. Therefore, industrial grade potentiometers were chosen to replace the existing components. The analog feedback is sufficient for the required accuracy of the system. The 3 axis, 4 pushbutton, 1 trigger, joysticks are industrial grade and commonly found in commercially available equipment. The joysticks are reliable and provide adequate versatility.
- The existing arm exhibited ratcheting motion when the hydraulics were in an over-running condition. Sun counterbalance valves, designed for use with over-running hydraulic circuits, were installed to eliminate the ratcheting. Utilizing the counterbalance valves reduces the stresses in the arm by eliminating the excessive accelerations encountered during ratcheting, and furthermore, allows for velocity control. Overpressure relief valves were installed to protect the structure of the arm. The hydraulic spool valves on the dump body were leaking and causing creep. A main flow poppet valve was installed to eliminate the creeping problem. The dual hydraulic reservoir

tanks were having problems equalizing due to plumbing complications. A single tank was used in place of the dual tanks and new plumbing installed.

Concerns

- The spherical bearings on the end joints of the *wrist* actuator are showing signs of excessive wear. Despite the structural work done to the *azimuth joint* and *short arm* section, there is significant flexure present in the robotic arm. Inspections of the arm should be conducted on a regular basis to identify any cracks. Several of the actuator pins are free floating. Allowing the pins to rotate without lubrication causes excessive wear. Therefore, the pins should be checked periodically.
- The poppet valve isolates the *dump body* valves. However, when the valves are needed, the poppet valve is opened providing pressure at the line side of every valve. Hence, creeping is present. The result is undesired creeping of the *dump body* components and periodic collision warnings issued by the controller.
- The tailgate occasionally does not close properly. The operator should verify that the tailgate is closed before driving the vehicle.

TRV STATUS MEETING

9/1/99

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Tom Aschwanden	Shop "B"	227-9668

Summary of Repairs Conducted on the Debris Removal Vehicle (DRV) During Field Testing for the Period 1/01/01 – 5/31/02

January 2001

Report
Auto dump function will not work.

Problem
The position sensor on the short arm joint drifted out of calibration due to mechanical forces causing loosening. This prevented the arm from reaching the targeted coordinates required due to travel limitations on the joint. Therefore, the motion sequencing could not be completed. The controller remained in the auto-dump mode trying to obtain an unreachable coordinate.

Fix
Re-calibrate the position sensor. Tighten the locking nut on the position sensor.

February 2001

Report
There appears to be reduced clearance between the *clamshell* and the *dump body*.

Problem
The position sensor on the long arm drifted. The controller sees the clearance as being greater than it really is. The position sensor has mechanically loosened and the axle bolt has started rocking on the setscrew.

Fix
The seats for the setscrews in the axle bolts were re-drilled and the setscrews replaced. In addition, the position sensors were replaced. The mechanics were trained on how to check all joint coordinates for slipping.

March 2001

Report
The position sensor coordinates have drifted again.

Problem
The robotic arm has several sections that are twisted, or bent; however, because the joints use spherical bearings, the mechanical system is still functional. The joint position sensors are mechanically connected to the axle bolts via a flexible coupling. Unfortunately, the axle bolts exhibit a procession rather than a simple rotation, due to the bent sections. The precession of the bolt exceeds the range of the flexible coupling

imposing an excessive force on the position sensor. The force is great enough to loosen the lock nut on the position sensor and allow the sensor to rotate.
Fix
The peak-peak displacement of the axle bolt was measured, throughout the joints range of motion, and compared to the flexible range of the coupling. It was decided that the potentiometer may be able to physically withstand the increased frictional force if it was restrained. Although the lifetime of the part may be reduced, restraining the potentiometer is the most cost effective solution at this time. The potentiometers were fixed to there mount using a Loctite brand hardening epoxy. The system was tested and physical movement previously observed between the potentiometer and mount was not detected.

May 2001

Report
The right joystick is not responding.

Problem
The machine runs fine from the left joystick. The right joystick is determined to be defective.

Fix
The joystick was sent to the factory for repairs.

November 2001

Report
The joint between the *short arm* and the *long arm* broke.

Problem
The axle bolt was broke during operation. It is unclear how or why the joint was damaged; however, it is assumed that the operator may have caused the *precrush door* to close on the joint causing the damage.

Fix
The joint was disassembled and a new axle bolt was fabricated. The axle bolt is a grade 8 bolt that is modified to interface with the position sensors. The joint was reassembled and the position sensor calibrated.

February 2002

Report
There is low clearance between the *clamshell* and the *dump body*. In addition, automated motion is being halted and responding erratically.

Problem

The long arm axle bolt rotated on the set screw. In addition, there was a problem with the backup battery in the controller. All motion profiles and control law coefficients that remain constant are burned to the EEPROM along with the rest of the compiled source code. However, constants that can be changed, such as positions for the presets modified by operators, are stored in RAM. The RAM is preserved through system power and the internal battery during power outages. Since the DRV is not run continually, the battery load is higher than the controller manufacturer had designed for. Therefore with a drained battery, when the system is shut down the desired positions for the presets are lost. The next time the system is initialized, the preset positions are not preserved. However, information always resides at memory locations, whether it is known or unknown there is always a sequence of zeros and ones. The result is an unpredictable motion profile upon commanding a preset requiring the operator to cancel the preset motion, by moving the joystick off-center or hitting the emergency stop, before damage can occur.

Fix
Set screw should be removed, the axle bolt seating hole dressed, and a new set screw installed. For the RAM backup battery the solution was to add an external battery pack that can be readily serviced and has an extended lifetime. The presets can be easily set by the operators after the batteries are replaced.

May 2002

Report
The *turntable* is not rotating.

Problem
The *turntable* motor is not responding. Hydraulic valves were swapped to verify that the motor was failing to operate.

Fix
The motor was replaced.

Appendix
B

AHMCT Advanced Highway Maintenance and Construction Technology Research Center

UC DAVIS Caltrans

The Debris Removal Vehicle Operator's Manual and Technical Reference

version 1.0
June 30, 2000

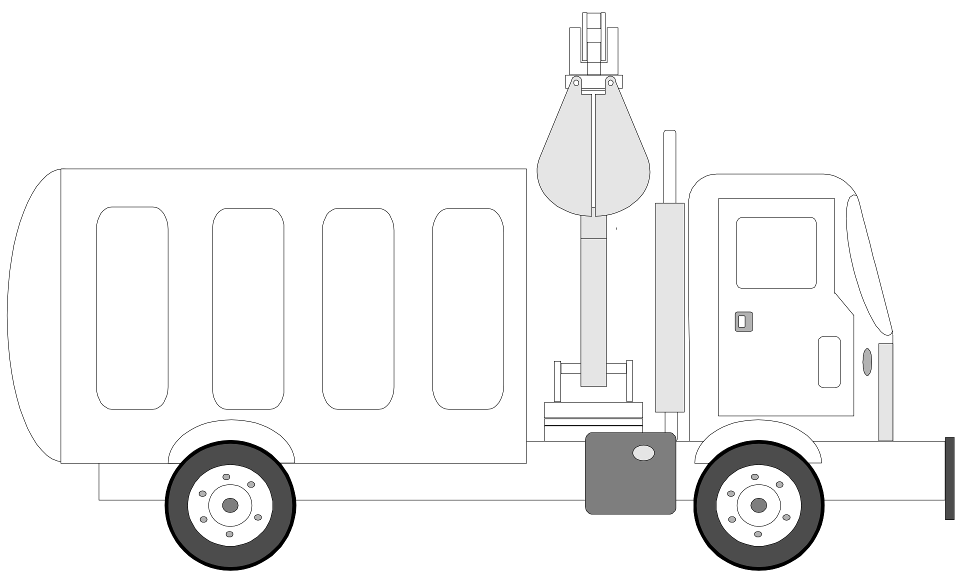

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TABLE OF CONTENTS

1 INTRODUCTION

2 MACHINE OPERATION

1: Theory Of Operation

The Caltrans/AHMCT Debris Removal Vehicle (DRV) is an operator controlled garbage collecting manipulator with limited automatic modes to assist in the most tedious tasks. In normal operation, the operator would program preset manipulator locations into the machine. These preset locations are accessible from joystick buttons P1 through P4. In the field, the operator would deploy the manipulator to a preset location by depressing the appropriate button. Then, the joystick would be used for fine adjustment of the manipulator in order to grab the debris. The buckets would then be closed. When the operator is satisfied that the payload is secure, the automatic dump action would be initiated with a special button combination. The manipulator would reposition itself over the compactor entryway, release the garbage, and reposition itself again to be ready for redeployment. The operator could then reposition the vehicle and restart the collection process again. If the operator determined that the garbage in the body needed to be compacted, the entire compaction cycle could be initiated by another convenient button combination from the operator joystick.

2: Machine Operation

2.1 Pre-operational System Checks

The following operational checks should be accomplished before system startup. It is assumed that the truck engine is running and the alternator voltmeter is reading greater than 12 volts.

2.1.1 Hydraulic Oil Level

Ensure that the hydraulic oil level, as seen from the sight glass on the oil tank, is visible and approximately halfway up the sight glass. If the level is below halfway, add Caltrans specification oil to the filler hole to bring the oil level up.

2.1.2 Arm Restraint Pins

There are two (2) restraint pins on the arm that are used to prevent unintended motion during transport. Ensure that the boom restraint pin is removed and placed in its holder and the spring clip replaced on the pin. Next, pull the azimuth pin and rotate the pin 90 degrees to place it in the unlocked position.

2.1.3 Machine Clearances

Ensure that there are no obstructions to either side of the truck. Additionally, ensure that the area above the compactor entryway is free from obstacles.

2.1.4 Emergency Stop

Ensure that at least one of the emergency stop buttons on the side of the operator's console in the truck cab is in the "IN" position.

2.1.5 System Power On

Place the power switch on the operator's console in the "ON" position. After the controller diagnostic checks have completed, the power light will begin to blink.

2.1.6 Joystick Calibration

The operator joysticks should be calibrated at the beginning of each shift. With the "*emergency stop*" placed in the "IN" position, place both the "*left guard*" and "*right guard*" toggle switches in the down position simultaneously. The "guard up" light should illuminate when the calibration procedure is complete.

2.2 System Operation

2.2.1 Joystick

The majority of motion commands for the arm is accomplished through the use of joysticks. The active joystick is determined via the position of the "joystick power" selector switch on the operator's console. Mounted on the joystick (Figure 1) are a trigger button and four (4) push buttons. These five (5) buttons allow the operator to perform preprogrammed, complicated operations. The joystick motion commands are listed on the table below:

Joystick Operation	Arm Function
x axis	long arm extend/retract
y axis	short arm up/down
z axis	azimuth rotation
trigger-x axis	raise/lower boom
trigger-y axis	extend/retract bucket
trigger-z axis	open/close bucket

The joystick button operations are listed in the table below. In order to use any of the button operations, the joystick must be in the center position. Moving the joystick off the center position will cancel the motion in progress.

Button Operation	Function
trigger + P1	automatic dump
trigger + P2	compact garbage
trigger + P3	stow arm
trigger + P4, P4	enter "preset" programming mode
P1	move to arm preset position 1
P2	move to arm preset position 2
P3	move to arm preset position 3
P4	move to arm preset position 4

The button combination "trigger + P4" is a special combination that activates the operator's special command mode. Pressing "trigger + P4" causes the *power light* to begin blinking. Pressing "P4" a second time then enters the preset programming mode. Selecting buttons P1, P2, P3, or P4 causes the computer to assign the current arm position to the specified button. The *power light* will then cease blinking. Pressing the assigned button will cause the arm to move to the preprogrammed position.

The button combination "trigger + P1" causes the arm to move from the current position to a position over the compactor entryway. The bucket is automatically opened, the garbage released, and the machine pivots to the side specified by the "machine side" toggle switch. The operator can then reposition the arm by selecting the preset positions programmed into buttons P1 thru P4.

The button combination "trigger + P2" initiates an automatic garbage compaction cycle. The precrush door is closed, the compactor cycled, and the door is then reopened. To shorten the compactor cycle time, the operator may slightly increase the engine speed. During the entire compactor cycle, the *compactor* indicator light will blink and the joystick commands will be disregarded by the machine controller.

The button combination "trigger + P3" moves the machine from its current position to the stowed position. In the stowed position, the boom and azimuth restraint pins can be reinstalled and the machine secured for transport or shutdown.

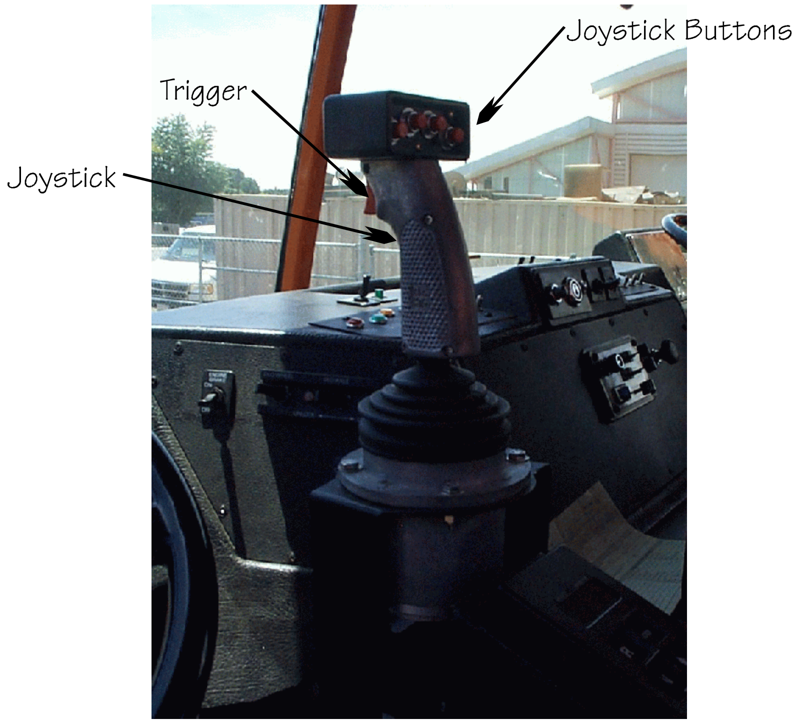


Figure 1: Joystick

2.2.2 Toggle Switches

On the operator's console are a large number of toggle switches (Figure 2). Their operation is listed below:

Switch	Function
Power On/Off	Turns the main power on or off
Dump Up/Down	Raises or lowers the dump body
Precrush Up/Down	Raises or lowers the precrush door
Compactor In/Out	Moves the trash compactor
Tailgate Open/Close	Opens or close the body tailgate
Left guard Up/Down	Raises or lowers the left trash fence
Right guard Up/Down	Raises or lowers the right trash fence
Machine Operation Right/Left side	Causes the machine to deploy from right or left side
Joystick power Right/Left side	Determines whether the right or left side joystick is active

Boom Up/Down	Raises or lower the boom
Turntable CW/CCW	Rotates the machine turntable clockwise (CW) or counterclockwise (CCW)

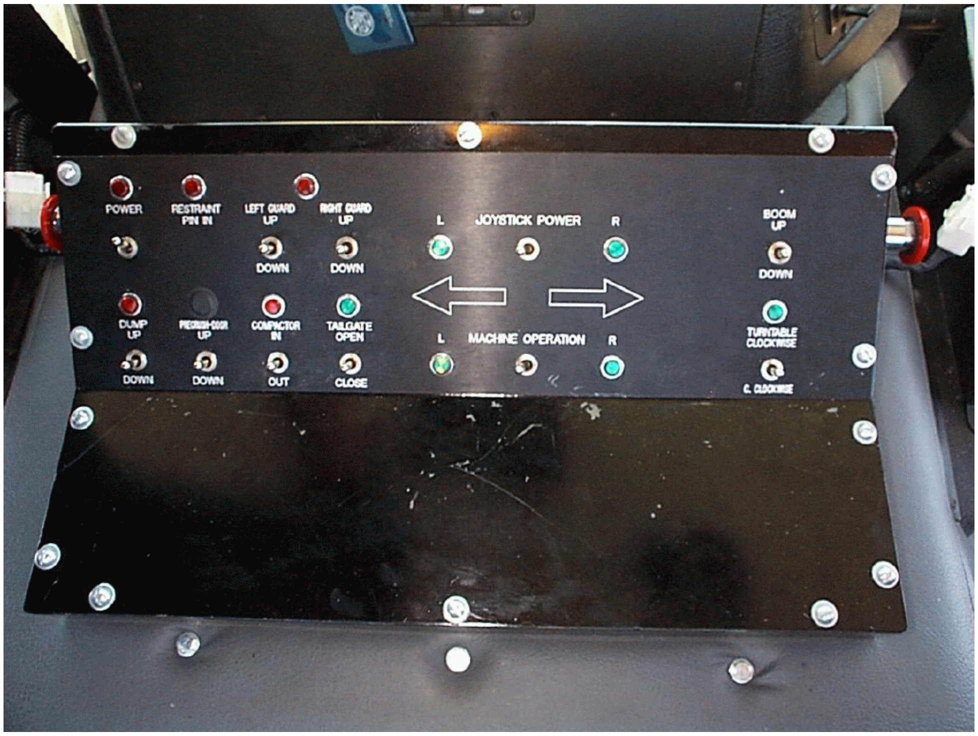


Figure 2: Cab console

2.2.3 Console Lights

On the operator's console are a number of indicator lights (Figure 2). Their meaning is listed in the table below. Note that a flashing light has a different indication than a solidly illuminating light.

Light	**Indication**
Power	power is on and system ready to be used
(blinking) Power	power is on and system is NOT ready to be used. Indicates emergency stop active.
restraint pin	azimuth restraint pin in locked position or boom restraint pin is not placed in unlocked position on holder.
(blinking) restraint pin	probable robot collision detected during automatic motion.
Gate up	With emergency stop active, indicates joystick calibration complete. With emergency stop inactive, a trash fence is in the raised position.

(blinking) Gate Up	System is executing an automatic motion profile.
Compactor	The compactor is not in the home position.
(blinking) Compactor	The compactor is in use.

2.3 System Shutdown

To shut the system down, press "trigger + P3" to stow the machine. Depress one of the emergency stop buttons on the side of the operator's console and then reinstall the boom and azimuth restraint pin. Then turn off the system power by placing the "power" switch in the "OFF" position.

Appendix A

Main Controller

A.1 Introduction

The entire DRV is controlled by an embedded computer (Figure A.1) located in the driver's side battery box. This computer has a 2-line LCD display and 10 function buttons. The complete operating characteristics of the manipulator can be altered through the use of the display and the function buttons. In normal use, the LCD display will show the current operating mode and/or any fault conditions that are detected. Additionally, the LCD can be programmed to display internal operating parameters that may be a useful aid in troubleshooting the system.

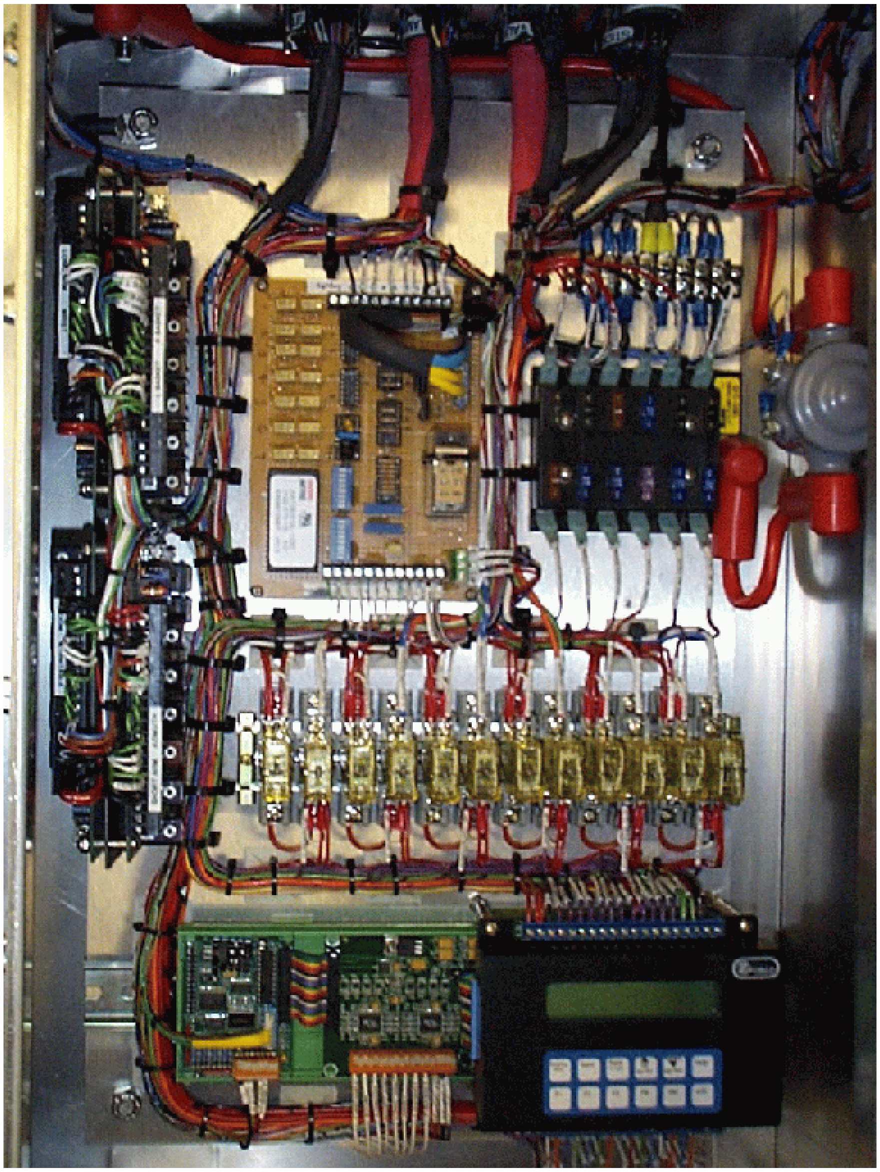


Figure A.1

A.1.1 Keypad

On the embedded computer is located a 10 button keypad composed of 2 rows of 5 buttons each. Only the first row of 5 buttons is used. Starting from the left, the buttons are labeled "menu", "item", "next", "↑", and "↓". The "menu" key cycles through all the available top-level menus. If the "item" key is pressed, then the sub-level items are displayed. Successive "item" key presses cycles though the available sub-level items. On each sub-level item are changeable parameter fields. Pressing "next" moves the cursor one field to the right. Using the "↑" and "↓" keys on a numeric parameter increments or decrements the parameter. Using "↑" and "↓" on other types of parameters just cycles through the available choices. Pressing "menu" records the parameter changes and makes them active. The menu hierarchy is detailed in Section A.1.2.

A.1.2 Menu Hierarchy

The menu hierarchy is listed below. For items with adjustable parameters, the acceptable range is listed in the *Parameter Range* column. The default values are shown in the *Default* column. **Under no circumstance, unless under direction of AHMCT Technical Support, should the parameters be modified. Machine damage or malfunction may result.**

Menu	**Item**	**Parameter Range**	**Default**
Global Parameters			
	PWM?	OFF, ON	ON
	Direct Drive?	N, Y	Y
	Jstick dband?	0...255	75
	PWM zero:	-50...50	-35
	Azi. loc out:	0.0...5.0	4.0
	Boom up pos:	0.0…20.0	9.0
	Boom loc out:	0.0...5.0	14.0
	Reload defaults?	No, Yes	No
	Reset hourmeter?	No, Yes	No
	Reset preset 1?	No, Yes	No
	Reset preset 2?	No, Yes	No
	Reset preset 3?	No, Yes	No
	Reset preset 4?	No, Yes	No
Display Control			
	Disp?	blank, time, op.time, coords, joystick, power, pvelo	time
Time/Date Menu			
	Date		
	Time		
Wrist Parameters			

	pos P gain:	0.0...100.0	0.80
	velo P gain:	0.0...300.0	2.0
	velo I gain:	0.0...100.0	1.8
	velo D gain:	0.0...100.0	0.0
	jstick scale:	0.0...35.0	30.0
	min limit:	0.0...180.0	20.0
	max limit:	0.0...180.0	100.0
Long Arm Parameters			
	pos P gain:	0.0...100.0	0.80
	velo P gain:	0.0...300.0	0.20
	velo I gain:	0.0...100.0	0.45
	velo D gain:	0.0...100.0	0.45
	jstick scale:	0.0...35.0	30.0
	min limit:	0.0...180.0	27.0
	max limit:	0.0...180.0	107.0
Short Arm Parameters			
	pos P gain:	0.0...100.0	0.80
	velo P gain:	0.0...300.0	0.35
	velo I gain:	0.0...100.0	0.7
	velo D gain:	0.0...100.0	0.02
	jstick scale:	0.0...35.0	12.0
	min limit:	0.0...180.0	30.0
	max limit:	0.0...180.0	81.0
Azimuth Parameters			
	pos P gain:	0.0...100.0	1.0
	velo P gain:	0.0...300.0	1.0
	velo I gain:	0.0...100.0	2.5
	velo D gain:	0.0...100.0	0.5
	jstick scale:	0.0...35.0	1.0
	min limit:	0.0...180.0	80.0
	max limit:	0.0...180.0	100.0
Boom Parameters			
	pos P gain:	0.0...100.0	1.0
	velo P gain:	0.0...100.0	2.4
	velo I gain:	0.0...100.0	1.5
	velo D gain:	0.0...100.0	1.75
Turntable Parameters			
	pos P gain:	0.0...100.0	1.50
	velo P gain:	0.0...100.0	5.0
	velo I gain:	0.0...100.0	2.0

	velo D gain:	0.0...100.0	0.150
	Max CCW pos:	0.0...100.0	20.0
	Max CW pos:	0.0...160.0	140.0
	Center pos:	0.0...100.0	80.0

Appendix B

Trouble Shooting

B.1 Introduction
The DRV utilizes an industrial controller. The controller has two types of inputs, analog and digital. The analog inputs are accomplished via the analog to digital (A-D) expansion board. The A-D board converts a varying input voltage into a digital integer value that the controller can use to evaluate signal amplitude. As an example, +5 Volts may be represented as the integer value 2048 in software. Likewise, there are two types of outputs, digital and analog. The analog outputs are accomplished via the digital to analog (D-A) expansion board. The conversions are done in hardware and interpreted in software. Digital inputs and outputs (IO) are accomplished with the digital IO interface on the controller and the digital IO expansion board. The digital I/O utilizes Transistor-Transistor Logic (TTL). ***Voltage readings should always be done with a digital voltmeter. Using a test light or jumpers could cause damage to the controller. A qualified person should be dedicated to the emergency stop switch before any testing is conducted.***

B.1.1 Analog Inputs
The joystick and position sensor inputs are the only analog inputs on this control system. The joystick and position sensor data can be verified by utilizing the controller. Press the menu button until the *Display Control* section is selected. Then use the up/down arrows to select either the *joystick* or *coords* for the position sensors. The menu button then must be pressed until the default screen is again displayed. The inputs can now be viewed. This not only guarantees that the input devices are working but that the controller is interpreting the data. If the display indicates that the input device is not working then the raw data can be checked. The analog inputs all range from 0 to +10 VDC. Joystick inputs can be checked with the engine off and the controller running. The position sensor inputs can be measured the same way however, no change can be observed. The position sensors are calibrated and should not be changed; Therefore, the hydraulic system should be running with the arm deployed on the opposite side of the vehicle from the controller so that the input can be safely measured as the joints move. Position sensor inputs can be measured from the terminal strip of the signal conditioning board located in the center of the controller and can also be observed via the LCD display.

B.1.2 Digital Inputs
The digital inputs are used for the toggle and limit switches. The controller input is normally high, +5 VDC, and then pulled low via a switch. For example when a switch contact is open, the conductor coming from the controller will measure a +5 VDC potential referenced to ground. When switched the input is pulled low, to ground, the input is considered active.

Warning !!!

Never connect any voltage source to the digital inputs, damage to controller will occur. Inputs are only switched to ground.

The digital inputs of the controller are normally high, nominally +5 VDC. The +5 VDC supply is integral to the controller and pulled high via an internal pull up resistor. In this state the logic gate input, which is high impedance and considered infinite for this purpose, is high. The input state is changed when the logic gate input changes to low. Therefore, switching it to ground changes the input. When the external switch is closed and the input is grounded, the pull up resistor limits the current and results in a +5 VDC drop. The voltage at the logic gate input is now the same as the ground reference, 0 VDC potential difference to ground. Figure B.1 illustrates a basic TTL filtered input with a pull up resistor.

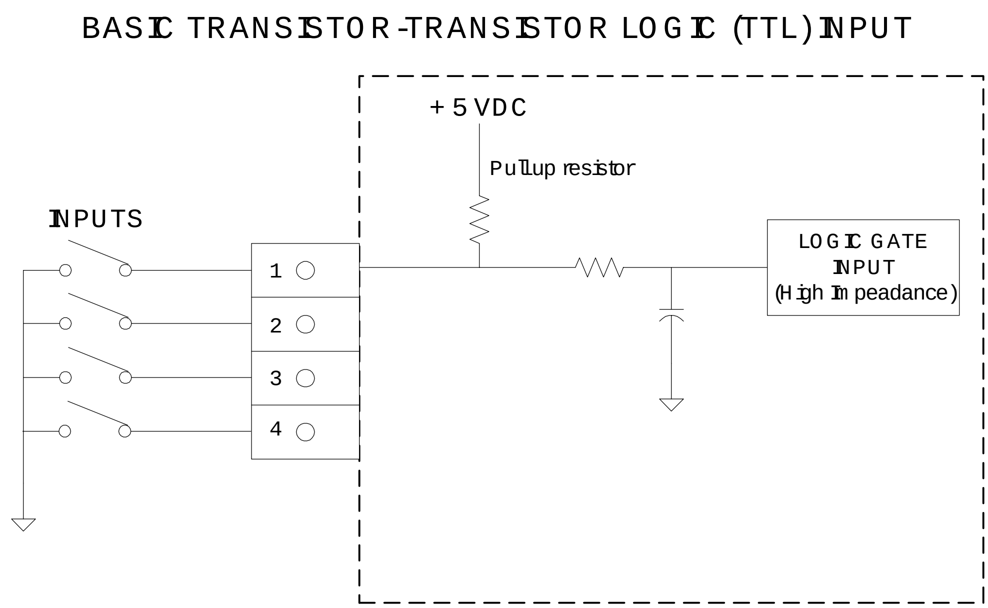


Figure B.1

The potential difference referenced to ground should be nominally +5 VDC at any of the digital inputs when the external switches are in an open position. When the switches are closed, the inputs should be 0 VDC. The signal can also be checked at the switch. With the switch in the open position there should be +5 VDC across the switch. With the switch in the closed position, the potential difference across the switch and referenced to ground should both be 0. If the inputs behave as described above they are working properly. If there is +5 VDC present but the switch does not drive the input to zero then there is a problem external to the controller. The problem may be wiring, termination, or the switch itself.

B.1.3 Digital Outputs

The digital outputs control the indicator lamps and the output relays. Both the relays and indicator lamps are supplied with a constant +12 VDC and switched, via the controller, to ground. The digital outputs of the controller are open collector. An open collector output works by sinking current. The load is supplied with a constant positive voltage with the ground- side connected to the controller output. The output is switched to ground via the internal output transistor.

Warning !!!

Never use a test light to check an output. Unexpected motion can result causing personal injury and/or damage to the equipment. If a test light were connected between the groundside of the load and ground, the load would be in series with the light and the circuit completed. The low impedance of the test light may allow enough current to flow to drive the output device. The *dump body* valves are driven by the digital outputs via a set of relays. The relays require little power and could easily be driven. Always use a digital voltmeter to check all voltages on the control system.

The *dump body* valves are driven off of the digital outputs via the control relays. The control relays coil is supplied with a +12 VDC voltage and the controller sinks the current to ground. The pole of the relay is +12 VDC and switched to energize the *dump body* valves. For each valve there are two relays, a primary and secondary. The secondary relay determines which direction the valve is to be driven. The primary relay supplies the +12 VDC to the pole of the secondary relay and serves as an on/off switch. An example of an open collector output is illustrated in Figure B.2. Refer to the wiring diagrams, *Appendix C*, for details.

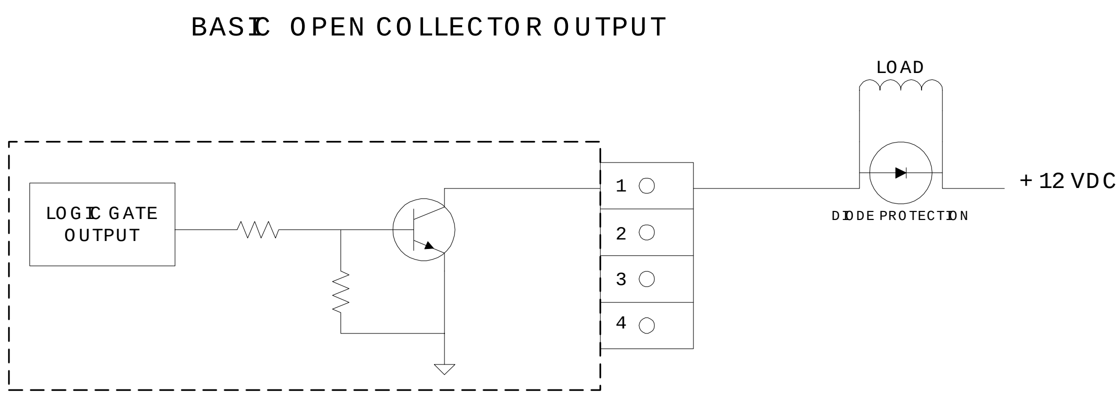


Figure B.2

B.1.4 Analog Outputs

The analog outputs are used to drive the Pulse Width Modulating (PWM) Amplifiers. The analog outputs from the D-A expansion board vary nominally from 0 to +10 VDC. To verify that the analog output is working a voltage reading, utilizing a digital voltmeter, can be taken while the joystick is being swept. This can be accomplished with the truck engine turned off such that the hydraulics are non-operational, accessory power on, and the controller energized and in the *system ready* state. On each amplifier board there is a LED next to each output transistor. Therefore to verify that the amplifiers are working, check that the output LED’s on the PWM boards are lighting as the corresponding input channel is set active. For example, if the joystick commands that the *short arm* be driven then the LED corresponding to the *short arm* channel should light up.

For fuse locations on the fuse block, reference Figure B.3 below. The fuse block is located in the main controller cabinet in the battery box on the left side of the truck.

Fault	**Probable Cause**
Power switch ON, power light OFF and no messages on LCD	1: Main circuit breaker open 2: Controller fuse blown
Power switch ON, power light OFF, and "HW Init Fail. No DAC found" on LCD	Digital to Analog Converter not found: possible board failure or loose interface cable
Power switch ON, power light OFF, and "HW Init Fail. No DIO found" on LCD	Digital I/O board not found: possible board failure or loose interface cable
Power switch ON, power light OFF, and "HW Init Fail. No ADC found" on LCD	Analog to Digital Converter not found: possible board failure or loose interface cable
"Power Failure" on LCD	Computer detected input power below 9.4 volts. Automatic shutdown to prevent damage.
"Crash in 1" on LCD	Software crash
"Crash in 2" on LCD	Software crash
"Crash in 3" on LCD	Software crash
"Crash in 4" on LCD	Software crash
"Crash in 5" on LCD	Software crash
"Emergency Stop" and time/date on LCD	Emergency stop button depressed.
"NOT Rdy: PWM Res" on LCD	Valve power amplifiers OFF and boom and/or azimuth restraint pins not removed.
"NOT Rdy: Res" on LCD	Boom and/or azimuth restraint pins not removed
"NOT Rdy: PWM" on LCD	Valve power amplifiers OFF.
"System Ready" and time/date on LCD	System is ready to be used.
1: "System Ready" on LCD 2: Arm does not respond to joystick input 3: Dump body hydraulic components functional 4: No lights on PWM amplifiers	PWM power fuse blown.
1: "System Ready" on LCD 2: Multiple joints (3 or 4) on arm do not respond to joystick input. 3: Dump body hydraulic components functional 4: All PWM amplifier boards have status lights operative.	Arm valve power fuse blown. Check both, there are two.

1: "System Ready" on LCD 2: Arm responds to joystick input 3: Dump body hydraulic components not functional.	1: Relay coil fuse blown 2: Dump body poppet valve not opening.
1: "System Ready" on LCD 2: Arm responds to joystick input 3: Multiple hydraulic components on dump body not functional.	Dump body valve power fuse blown. Check both, there are two.
1: "Emergency Stop" on LCD 2: Emergency stop buttons (2) not depressed 3: No sound from PTO hydraulic pump	PTO/EStop fuse blown
1: "System Ready" on LCD 2: Arm responds to joystick input 3: Hydraulic components on dump body functional 4: No indicator lamps on cab console	Indicator lamp fuse blown
1: "System Ready" on LCD 2: Arm does not respond to joystick input 3: Dump body hydraulic components functional	1: PC board fuse blown 2: PC board failure
1: "System Ready" on LCD 2: One side joystick functional, other side nonfunctional 3: Console indicator lamp indicates successful joystick switch over.	Joystick relay fuse blown
1: "System Ready" on LCD 2: Arm joint can move in only one direction	1: Hydraulic valve malfunction

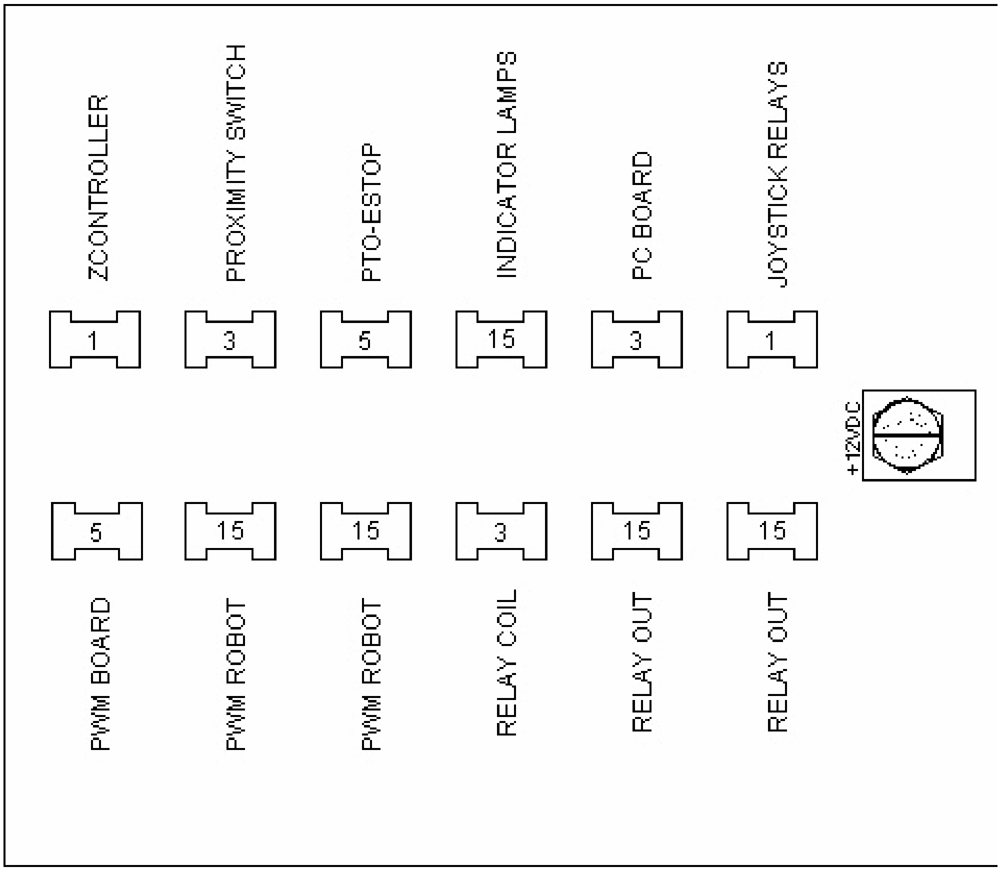
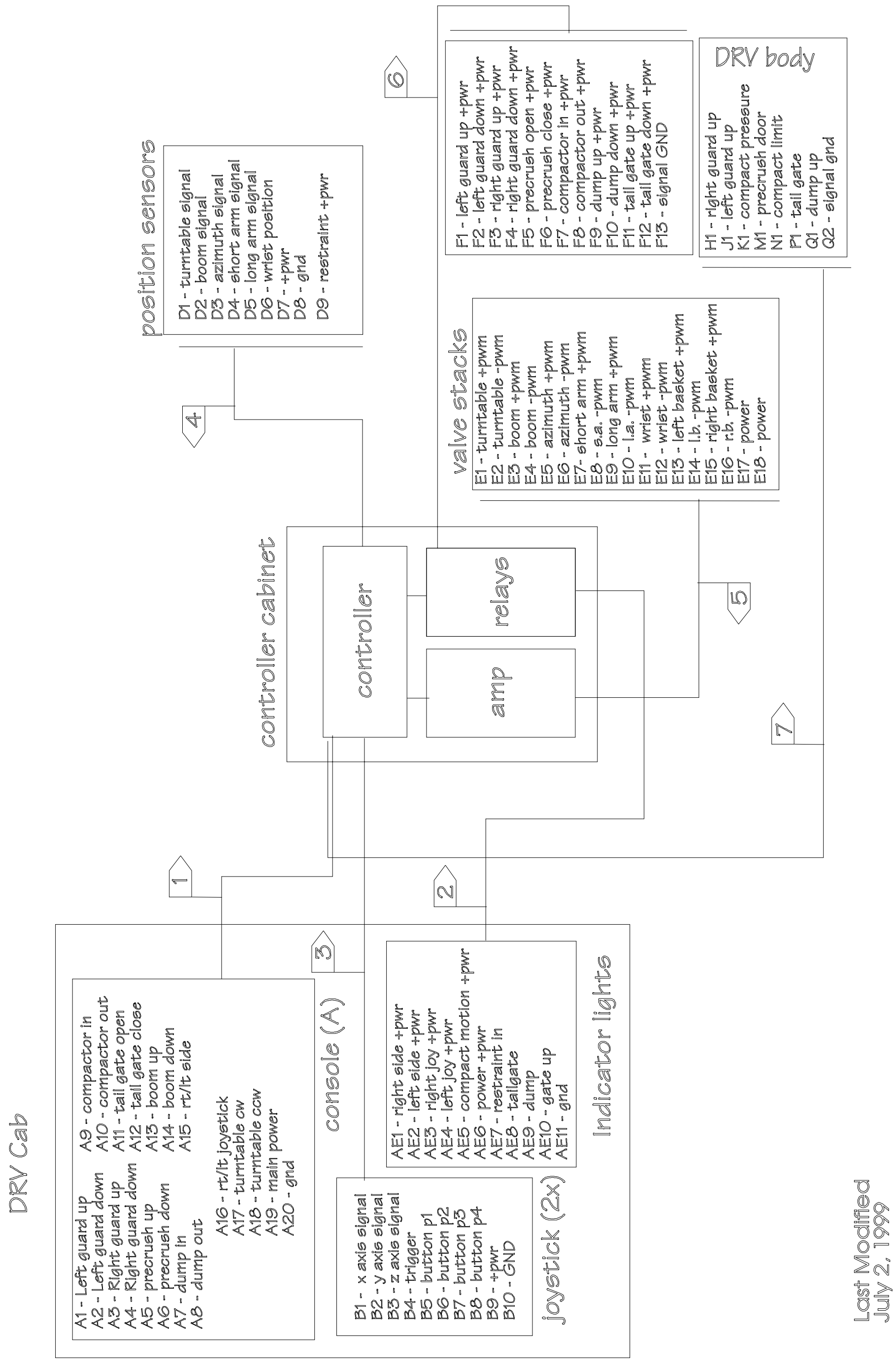


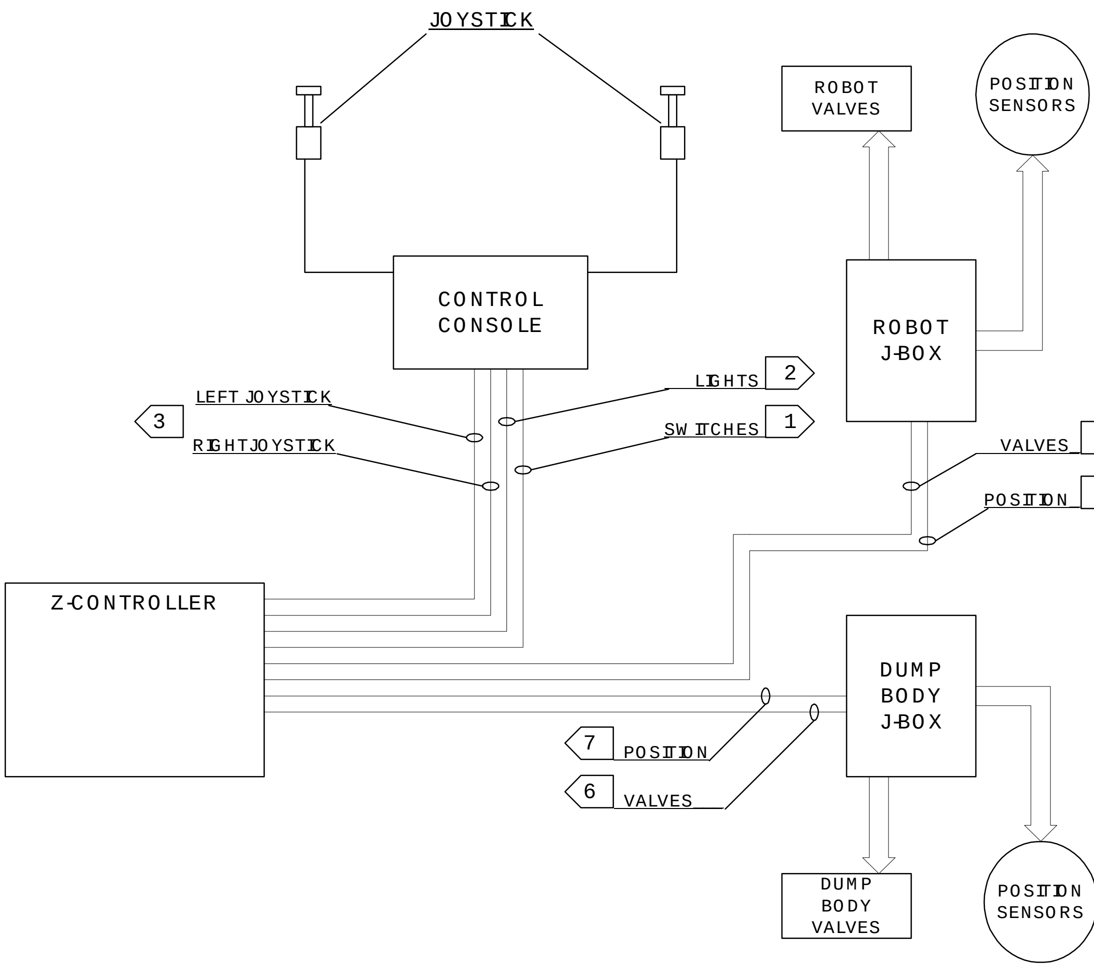
Figure B.3: Fuse locations

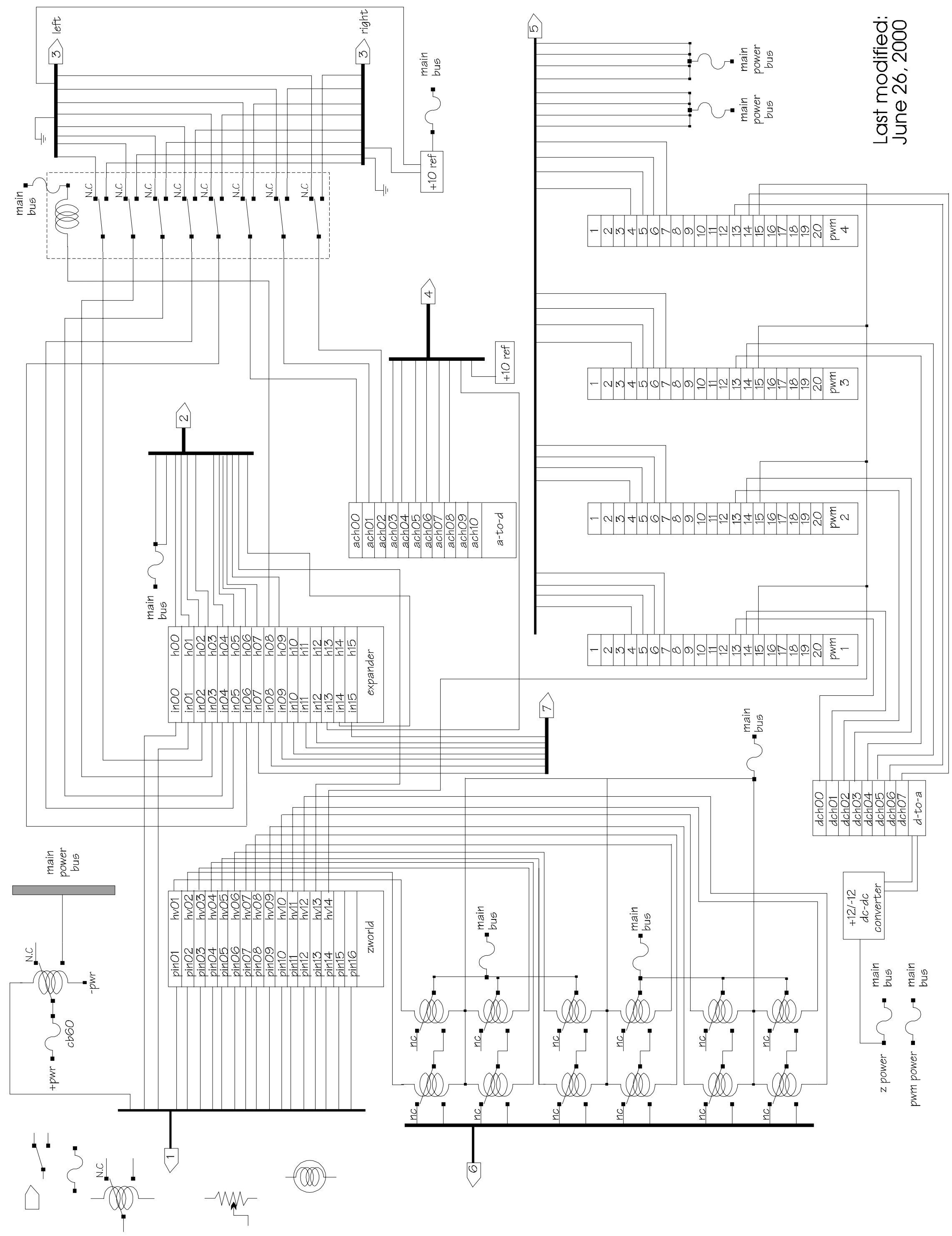
Appendix C

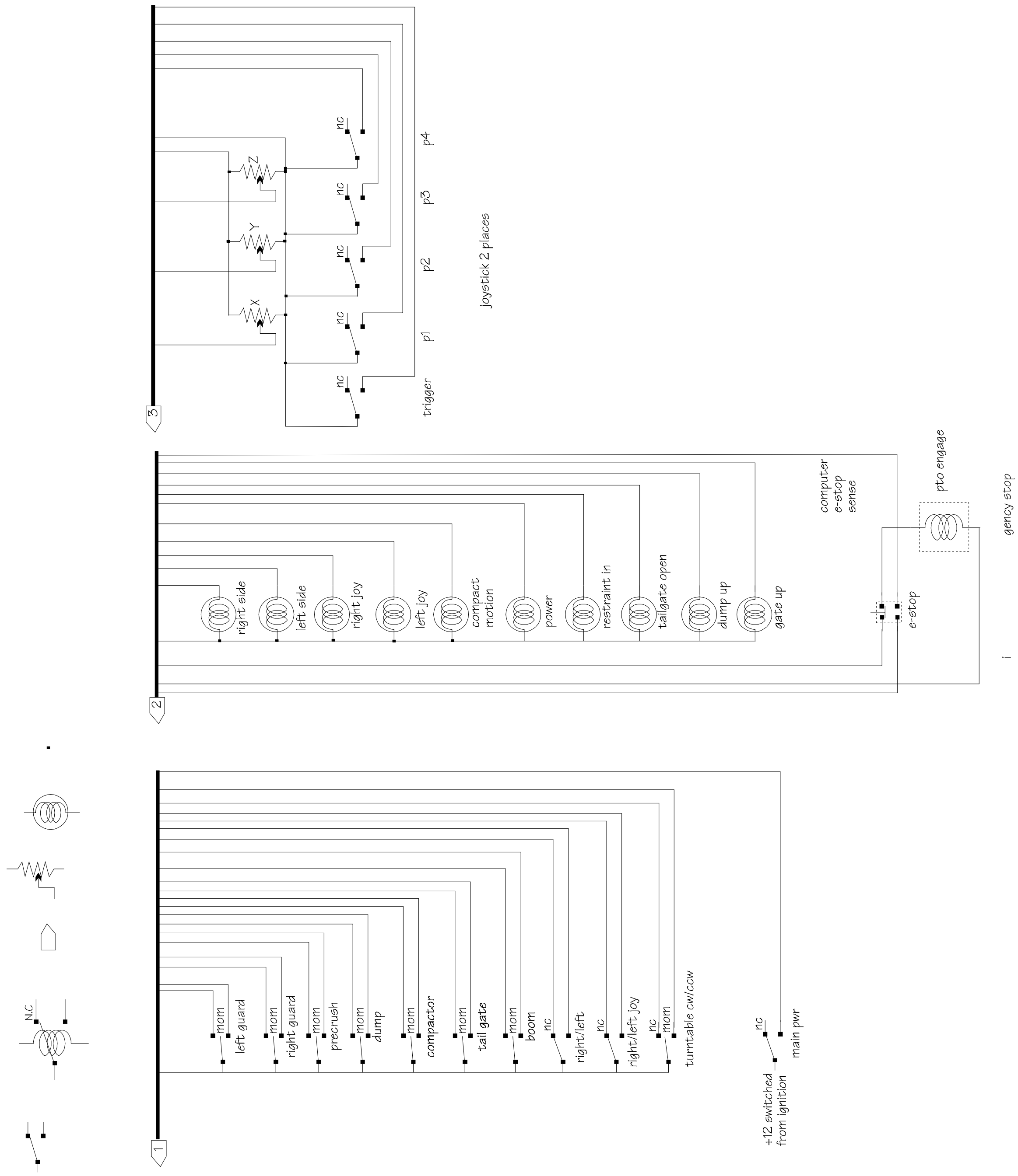
Wiring Diagrams


position sensors
D1 - turntable signal
D2 - boom signal
D3 - azimuth signal
D4 - short arm signal
D5 - long arm signal
D6 - wrist position
D7 - +pwr
D8 - gnd
D9 - restraint +pwr
F1 - left guard up +pwr
F2 - left guard down +pwr
F3 - right guard up +pwr
F4 - right guard down +pwr
F5 - precrush open +pwr
F6 - precrush close +pwr
F7 - compactor in +pwr
F8 - compactor out +pwr
F9 - dump up +pwr
F10 - dump down +pwr
F11 - tail gate up +pwr
F12 - tail gate down +pwr
F13 - signal GND
DRV body
H1 - right guard up
J1 - left guard up
K1 - compact pressure
M1 - precrush door
N1 - compact limit
P1 - tail gate
Q1 - dump up
Q2 - signal gnd
valve stacks
E1 - turntable +pwm
E2 - turntable -pwm
E3 - boom +pwm
E4 - boom -pwm
E5 - azimuth +pwm
E6 - azimuth -pwm
E7- short arm +pwm
E8 - s.a. -pwm
E9 - long arm +pwm
E10 - l.a. -pwm
E11 - wrist +pwm
E12 - wrist -pwm
E13 - left basket +pwm
E14 - l.b. -pwm
E15 - right basket +pwm
E16 - r.b. -pwm
E17 - power
E18 - power
controller cabinet
controller
relays
amp
1
2
3
4
5
6
7
DRV Cab
console (A)
A1 - Left guard up
A2 - Left guard down
A3 - Right guard up
A4 - Right guard down
A5 - precrush up
A6 - precrush down
A7 - dump in
A8 - dump out
A9 - compactor in
A10 - compactor out
A11 - tail gate open
A12 - tail gate close
A13 - boom up
A14 - boom down
A15 - rt/lt side
A16 - rt/lt joystick
A17 - turntable cw
A18 - turntable ccw
A19 - main power
A20 - gnd
joystick (2x)
B1 - x axis signal
B2 - y axis signal
B3 - z axis signal
B4 - trigger
B5 - button p1
B6 - button p2
B7 - button p3
B8 - button p4
B9 - +pwr
B10 - GND
Indicator lights
AE1 - right side +pwr
AE2 - left side +pwr
AE3 - right joy +pwr
AE4 - left joy +pwr
AE5 - compact motion +pwr
AE6 - power +pwr
AE7 - restraint in
AE8 - tailgate
AE9 - dump
AE10 - gate up
AE11 - gnd
Last Modified
July 2, 1999

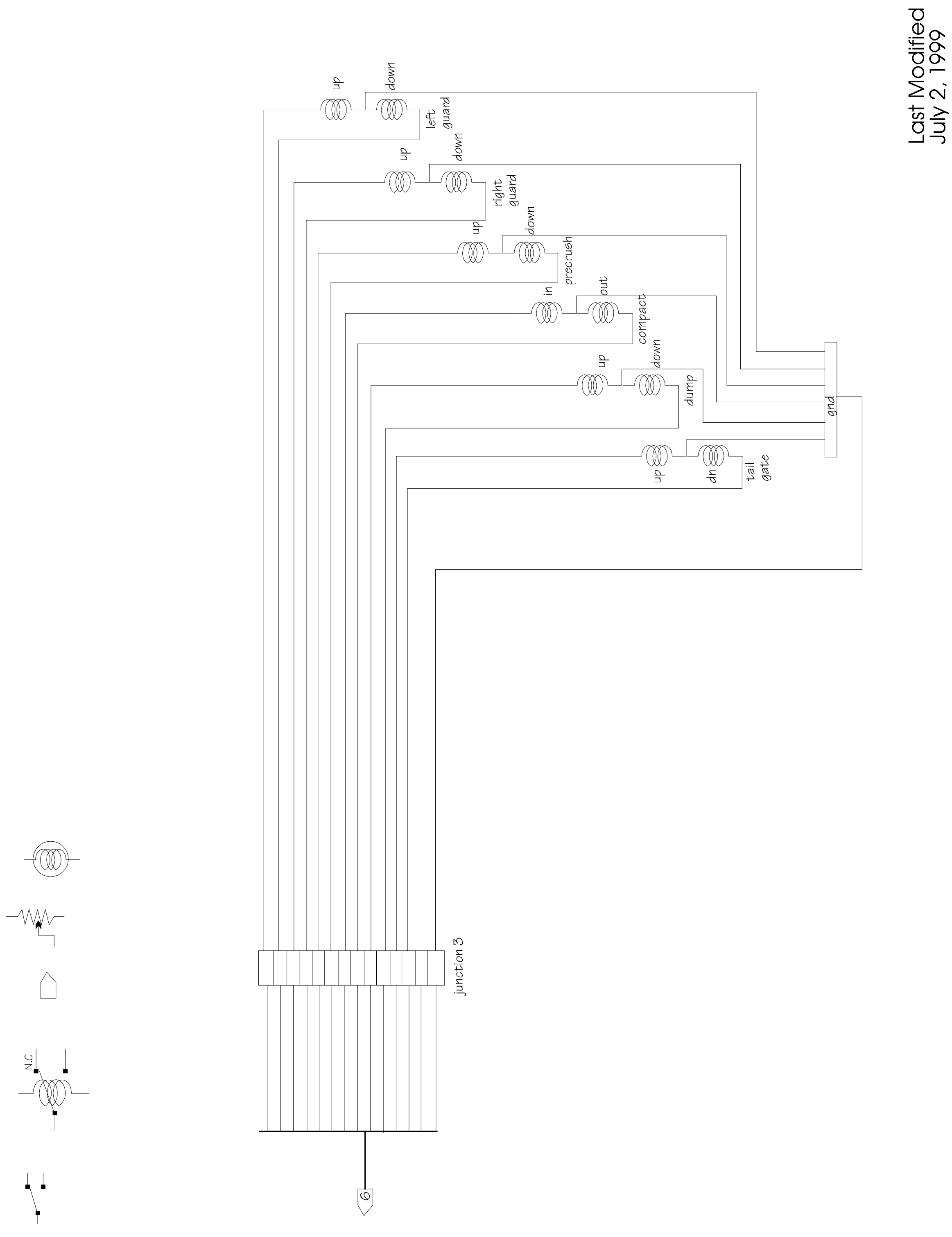
Cable Routing

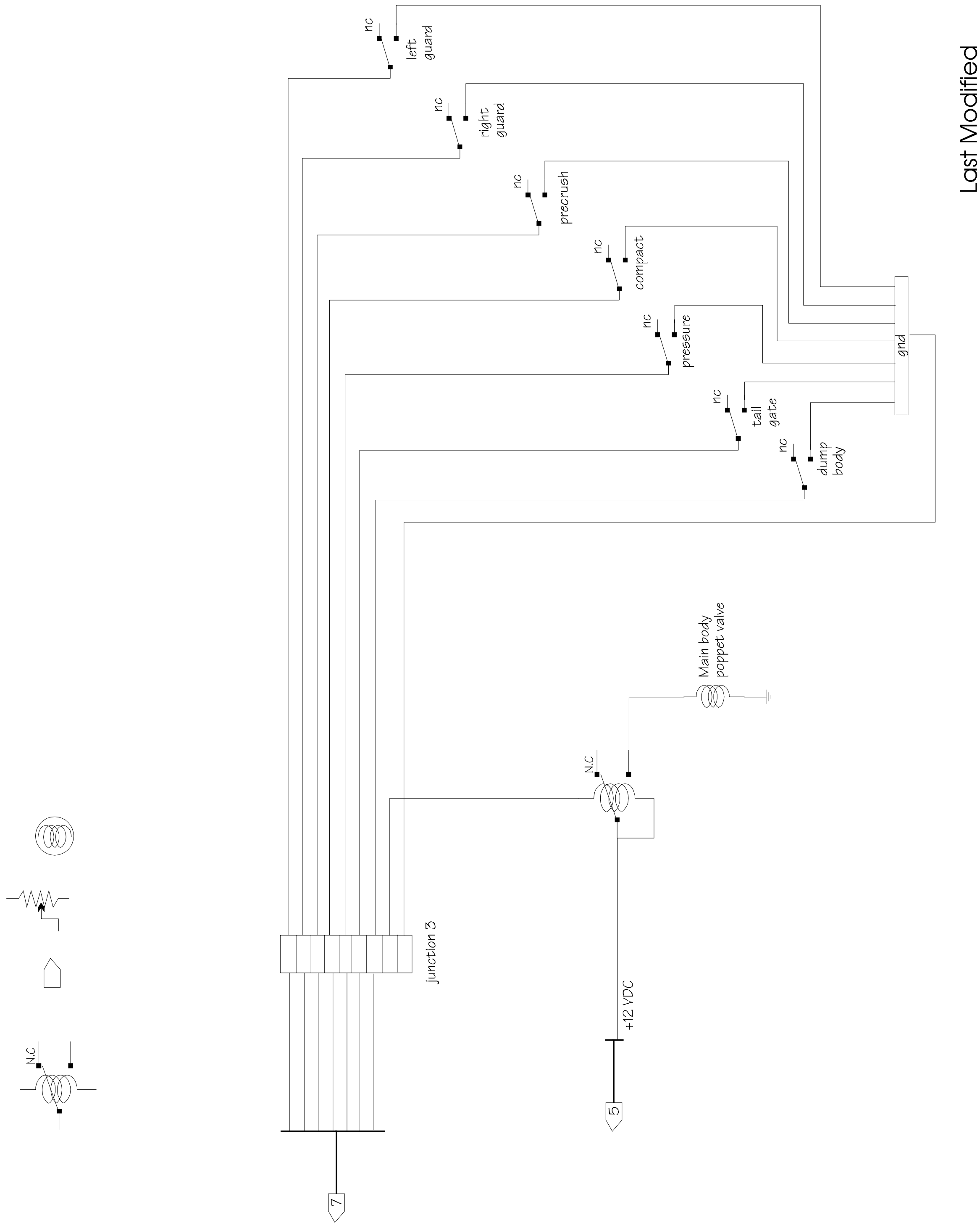


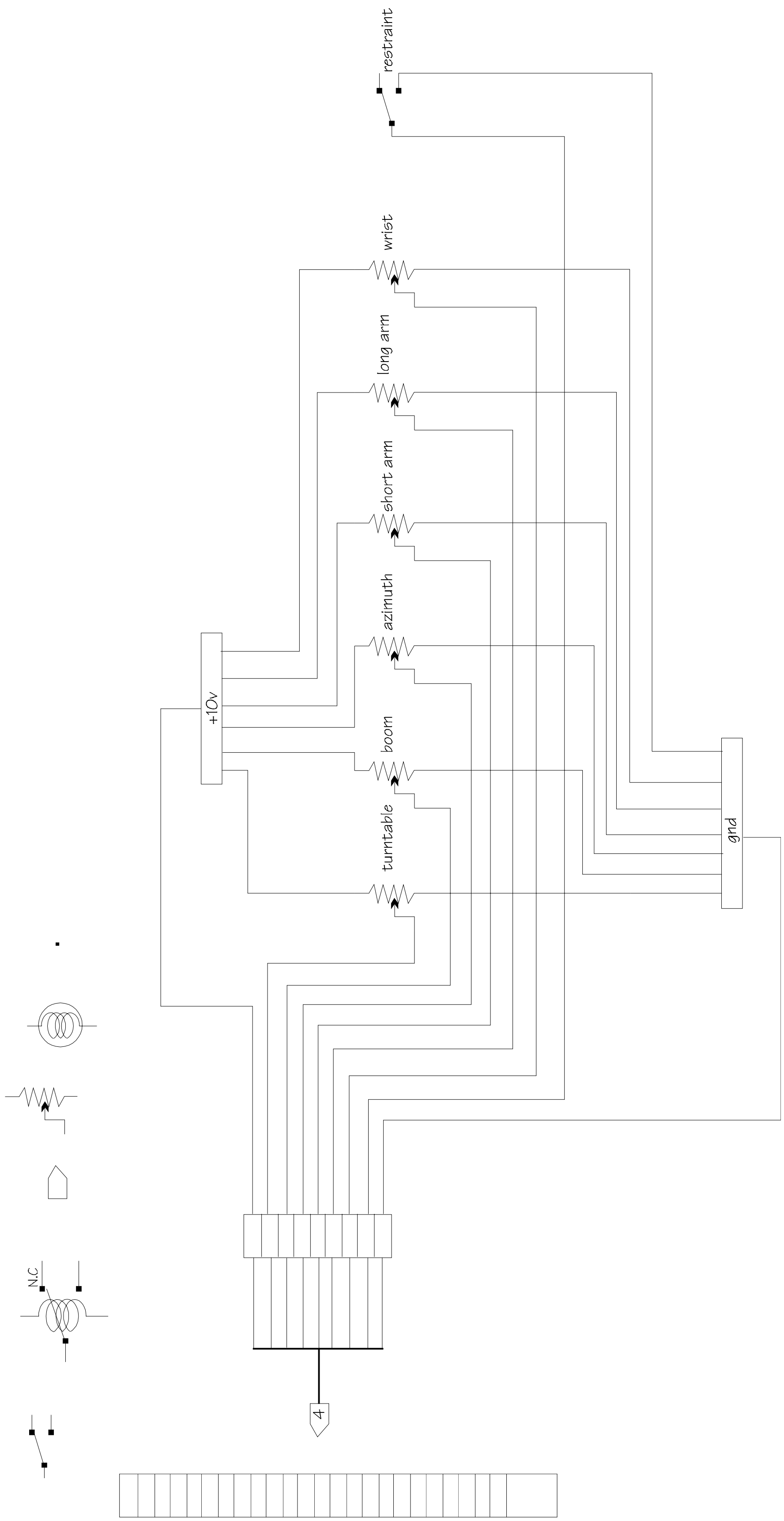

Last modified:
June 26, 2000
left
right
main bus
main power bus
+10 ref
N.C
pwm 4
pwm 3
pwm 2
pwm 1
a-to-d
expander
zworld
d-to-a
+12/-12 dc-dc converter
z power
pwm power
cb60
+pwr
-pwr

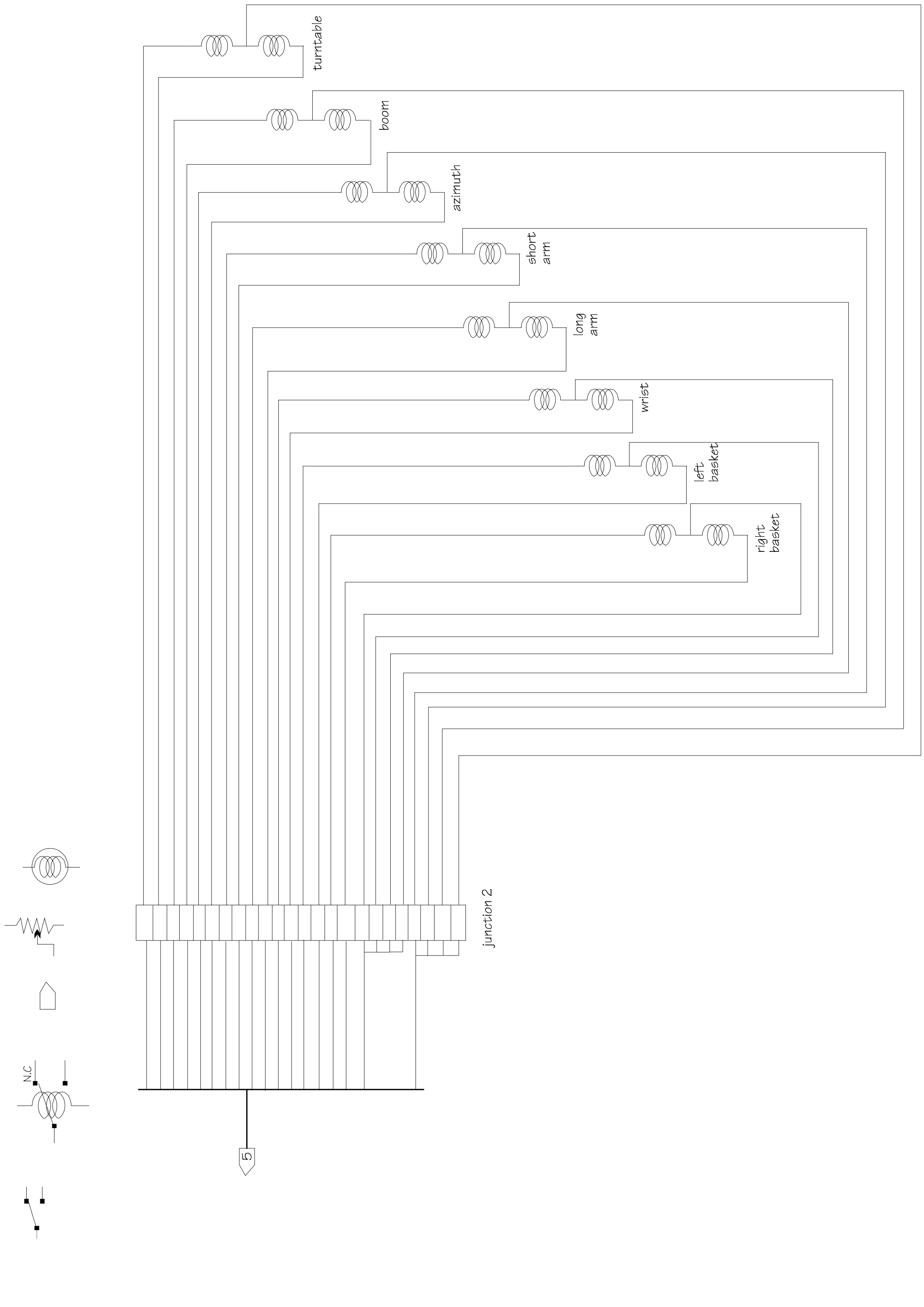


nc
Z
Y
X
trigger
p1
p2
p3
p4
joystick 2 places
3
right side
left side
right joy
left joy
compact motion
power
restraint in
tailgate open
dump up
gate up
computer e-stop sense
pto engage
e-stop
gency stop
2
N.C.
mom
left guard
right guard
precrush
dump
compactor
tail gate
boom
right/left
right/left joy
turntable cw/ccw
+12 switched from ignition
main pwr
1


Last Modified
July 2, 1999
up
down
left guard
up
down
right guard
up
down
precrush
in
out
compact
up
down
dump
up
dn
tail gate
gnd
junction 3
6
N.C


nc
left guard
nc
right guard
nc
precrush
nc
compact
nc
pressure
nc
tail gate
nc
dump body
gnd
Last Modified
June 26, 2000
Main body poppet valve
N.C
junction 3
+12 VDC
5
7
N.C


restraint
wrist
long arm
short arm
azimuth
boom
turntable
+10v
gnd
N.C.
4


turntable
boom
azimuth
short arm
long arm
wrist
left basket
right basket
junction 2
N.C
5

CONSOLE SWITCHES
8459 22 AWG

PIN:	COLOR:	FUNCTION:
A	white/black	tailgate-close
B	black/white	turntable-clockwise
C	blue	tailgate-open
D	blue-black	boom-down
E	red/white	turntable-counter clockwise
F	green/white	precrush door-up
G	red/black	compactor-in
H	black	power on
J	orange	dump body-down
K	blue/white	precrush door-down
L	green/black	compactor-out
M	black/red	left guard-up
N	red/black/white	common ground-switches
P	green	dump body-up
Q	white/black/red	left joystick
R	orange/black	boom-up
S	white/red	left guard-down
T	orange/red	right guard-up
U	white	ground
V	red	spare
W	blue/red	right guard-down
X	red/green	right machine
Y	black/white/red	right joystick
Z	orange/green	left machine

INDICATOR LIGHTS
8624 16 AWG

PIN:	COLOR:	FUNCTION:
A	blue/black	right joystick
B	orange/black	left machine
C	red/black	compactor motion
D	blue/red	e-stop ground
E	blue	turn table
F	black/red	guard
G	green	tailgate
H	blue/white	spare
J	green/white	PTO ground
K	red	power
L	black/white	left joystick
M	white	ground
N	green/black	right machine
P	black	+12VDC Lamps
R	orange/red	e-stop input
S	orange	restraint pin
T	red/white	+12VDC PTO

NOT CONNECTED
white/red
white/black

DUMP BODY SENSORS
9457 20 AWG

PIN	COLOR	FUNCTION
A	gray	spare
B	purple	pressure
C	black	spare
D	yellow	compact limit
E	orange	right guard up
F	blue	tailgate open
H	red	+12 for proximity switch
J	tan	spare
K	pink	precrush door open
L	dark brown	left guard up
M	white	ground

NOT CONNECTED
green

DUMP BODY VALVES
8624 16 AWG

PIN	COLOR	FUNCTION
A	green/white	pre-crush door up
B	white/black	tailgate close
C	black	spare
D	blue/red	right guard down
E	blue	tailgate open
F	black/red	left guard up
G	green	dump body up
H	blue/white	pre-crush door down
J	blue/black	spare
K	orange/black	spare
L	green/black	compactor out
M	red/black	compactor in
N	red	spare
P	white/red	left guard down
R	orange/red	right guard up
S	orange	dump body down
T	white	ground

NOT CONNECTED
Red/white
Black/white

All Dump Body Valves are common ground and +12VDC switched through the control relays in the control box (ZBOX).

JOYSTICKS
83569 22 AWG

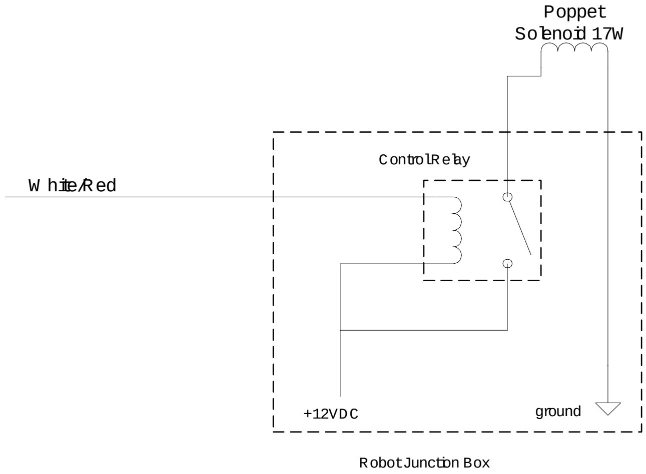
PIN:	COLOR:	FUNCTION:
A	green/white	spare
B	blue/white	spare
C	black/red	spare
D	black	ground
E	white/red	spare
F	white/black+shield	common
G	red	+ 10VDC
H	white	PB 2
J	orange/black	Z-axis
K	orange	PB 3
L	red/white	spare
M	black/white	spare
N	green	PB 1
P	blue	PB 4
R	red/black	X-axis
S	green/black	Y-axis
T	blue/black	trigger

ROBOT POSITION
83569 22 AWG

PIN	COLOR	FUNCTION
A	blue	ground
B	orange/black	boom
C	black/white	turntable
D	red/white	spare
E	green	short arm
F	black/red	wrist
G*	white/red	poppet
H	red	+ 10VDC
J	blue/red	spare
K	red/black	spare
L	white/black	azimuth
M	shield	shield
N	orange	restraint
P	black	spare
R	blue/white	spare
S	white	ground
T	orange/red	long arm

NOT CONNECTED:
green/black
green/white
blue/black

- Poppet valve added to shut off hydraulic flow to dump body. +12VDC for control relay and valve power provided via the Robot PWM cable.
- Poppet control relay coil is +12VDC common with a switched ground.
- Poppet valve is common ground and +12VDC switched.



ROBOT PWM VALVES
83719 16AWG

PIN	COLOR	FUNCTION
A	blue/black	boom down
B	orange/black	boom up
C	red/black	azimuth counter clockwise
D	white/red	wrist up
E	white/black	azimuth clockwise
F	blue/red	long arm down
G	blue	left basket open
H*	red/white	turntable counter clockwise
J	green	short arm up
K	red	+ 12 VDC
L	black	+ 12 VDC
M*	black/white	turntable clockwise
N	blue/white	right basket close
P	green/black	left basket close
R	black/red	wrist up
S	orange/red	long arm up
T	orange	short arm down
U	white	shield
V	green/white	right basket open

Pin K (red), L (black) provide +12vdc for all valves (except turntable, see note below) associated with robot arm. All other references are grounds being switched through the Pulse Width Modulating (PWM) amplifier.

Extreme Caution: Do not connect any wires to ground (except turntable common). Grounds must be switched through the PWM. Connecting wires to ground could cause unexpected motion and/or damage to the equipment.

* Turntable is common ground, +12VDC switched. Pin, H (red/white),
M (black/white), are +12 VDC switched through relay in controller. Refer to wiring schematics for detail.

Appendix D

Hydraulic Schematics

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(information to be provided by CalTrans)

Appendix E

Cable Specifications

Cable Specification

Belden #	Cond.	AWG	Shielding
1. 8459	25	22	none
2. 83719	19	16	overall foil & braid
3. 83569	19	22	overall foil & braid
4. 8624	19	16	none
5. 9457	12	20	none

Use:

1. console toggle switches
2. robot PWM valves
3. a. joystick1
   b. joystick2
   c. robot position sensors
4. a. dump body valves
   b. console indicator lamps & E-stop
5. dump body sensors

Note:
Belden cable was used since it is readily available and reliable. Equivalent cable may be used for replacement. Care should be taken in considering the specification of an equivalent cable. Wire gage and shielding should not change.

Appendix F

Electrical Parts List

Parts List

	ZWorld Part #
ZWorld Industrial Controller PK2200	101-0093
ZWorld Analog-Digital Converter XP8500	101-0022
Zworld Digital-Analog Converter XP8900	101-0273
ZWorld Digital I/O Expansion Board XP8100	101-0181

ZWorld
2900 Spafford Street
Davis, CA 95616-6800
(530) 757-3737
1 800 362-3387
http://www.zworld .com

	Newark Part #
Idec Relays SPDT 12VDC	96F3918
Relay Socket Snap Mount SH1B-05	96F3991
Relay Hold Down Spring SY2S-02F1	96F6503
Position Sensor Bourns 1-Turn 0-5K 6657S-1-502	12F7109
Omron Relays 4PDT 12 VDC G6A-434P-ST-US	52F3896

Newark Electronics
2020 Hurley Way
Sacramento, CA 95825-3214
1 800 4NEWARK

	Ditco Part #
PWM Amplifiers 8 Bit 2Channel	EH101

Ditco Inc.
106 E Titus Street
Kent, WA 98032
253 854-1002

	P-Q Controls Model #
Joystick Three Axis	Model 220

P-Q Controls, Inc.
95 Dolphin Rd.
Bristol, CT 06010
203 583-6994

Appendix G

Hydraulic Parts List

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(information to be provided by CalTrans)

Appendix C

Changing Timer Pre-sets on the LCSM II

The PLC must be turned on to change the pre-set timer values and the updated values only exist while the system is on. Once the PLC is turned off, the default timer values will be restored at next power-on.

With the system turned on, press the CHG PRE button. The menu should appear as below:

TIMER A 0600
TIMER B 0600

The + or – key will select between TIMER A and TIMER B. do not go beyond TIMER B. If you do, use the – key to get back.

Once the correct timer is selected, press the ENT key to change fields to the Vmemory (timer value). Remember that the timer value is in 1/10ths of a second. Default value is 0600 or 60 seconds.

The → ← buttons move the cursor within the numeric placeholders.

Again use the + or – buttons to change the numeric value of the selected placeholder.

Once the correct timer values are programmed, press the ENT button to return to Timer selection or the MSG button to return to the default screen. The new values will stay active until the power is turned off.

Example

1. Turn on PLC
2. Press the CHG PRE button
3. Timer A is selected by default
4. Press ENT to move cursor to the timer values
5. Move the cursor with the → ← buttons to the correct placeholder
6. Use the + - keys to set the appropriate time
7. Continue to step 8 to set Timer B or Press MSG to return to default menu
8. Press ENT to return to Timer selections
9. Use the + button to select Timer B
10. Press ENT to change fields
11. Use the → ← buttons to switch between placeholders
12. + or – to set the appropriate time
13. MSG to return to default screen

Appendix D

Automated Cone Machine Safe Operation

1.1 Overview

The ACM is an automated piece of equipment that places and retrieves traffic cones. It allows an operator to perform their task without working outside the vehicle. A solid state controller is used to automate the process. Unlike a personal computer, this solid state controller initializes quickly and can be power cycled on and off at any time. The ACM uses electric and hydraulic power. All electric power is the nominal truck voltage 12 VDC. As with all automated equipment, components can move unexpectedly therefore, care should be taken to stay out of the equipment's work area unless the system is turned off.

1.2 Safety Features

The ACM is equipped with Emergency Stop switches located in the cab center control console, left seat bucket, and right seat bucket. The E-Stop switches stop all motion on the ACM. Depressing any one of the E-stop switches will immediately stop the movement of the machine.

The hydraulic reservoir is located behind the cab on the sign board support rack. The main shut off valve is on the side of the tank on the passenger side of the vehicle. The shut off valve is normally left in the open position but in the case of a hydraulic leak should be closed.

The truck has wide angle mirrors installed on both sides of the vehicle. The operator should use these mirrors and check their blind spots to insure it is safe to deploy the ACM components. The ACM components should not be deployed when personnel or obstructions are in any of the equipments work space.

There is an ABC rated fire extinguisher mounted on the vertical post in the left seat bucket.

1.2.1 Safety In The Equipment Work Space

Slow moving equipment is often under-estimated as a safety concern. Operators may develop an over confidence that if caught in between slow moving machinery they will have the time to move clear. Unfortunately, this confidence often results in injury. Operators are less cautious when working around slow moving machinery and can easily find themselves trapped. The left and right *drop boxes* deploy slowly. Operators should make sure that these areas are clear before deploying or retrieving either *drop box.*

There are many moving parts in the *lateral conveyor*, *cone stack,* and *stowage system* regions located in the middle of the truck (*figure 1.0*). These areas should be clear of personnel and any obstructions before the system is turned on and operated and remain clear during operation.

There is a *primary funnel* located on each of the corners of the vehicle. Operators should verify that these areas are clear before energizing the system and deploying the *primary funnels*.

1.2.2 General Safety Rule

The ACM control system should not be turned on or running with obstructions or personnel in any of the regions where the automated equipment is located or could be deployed.

The control system can be shut down and re-started without any lag or start up time. If there are any concerns with safety of personnel or equipment the system should immediately be turned off.

Work on the ACM equipment should only be conducted by certified personnel.

Operators of the ACM must be trained and familiar with the machine before using it in traffic conditions. Safe operation is mandatory.

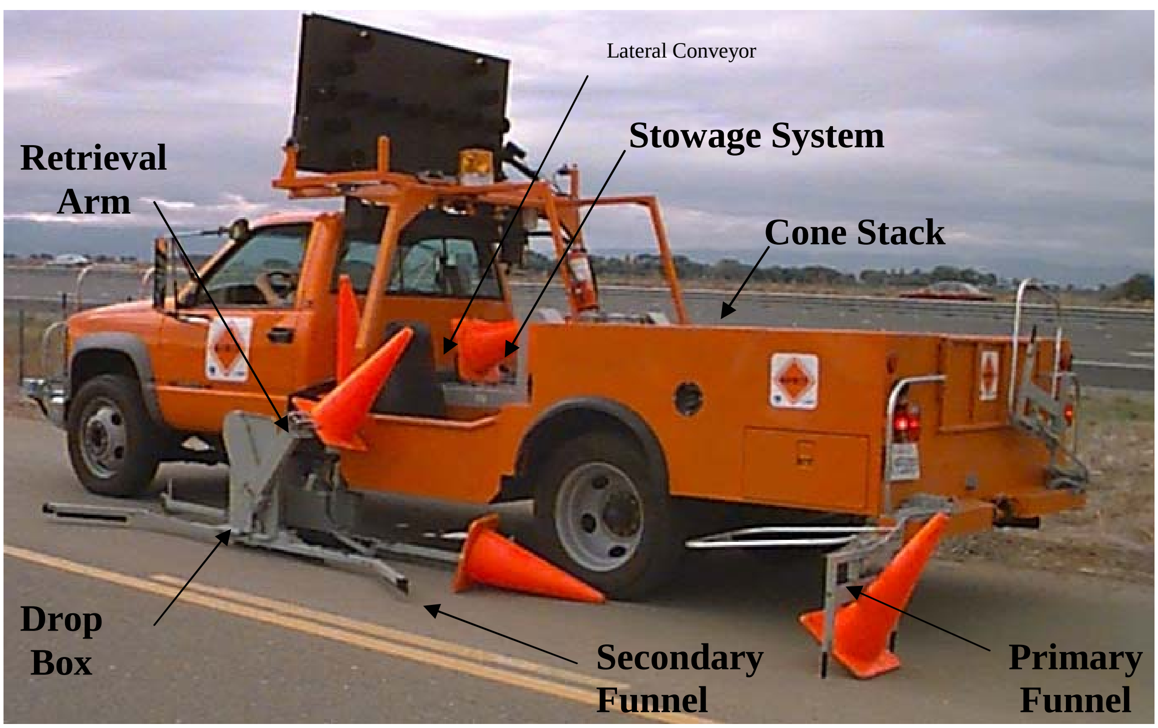

Figure1.0 AHMCT Automated Cone Machine

1.3 Equipment Checkout

In order to reduce the opportunity of damage and/or malfunction, a thorough check out of the machine should be done prior to each use.

1.3.1 Pre-Operational Checkout

1. Pre-operational vehicle checkout
2. Visually inspect condition of the ACM components
3. Hydraulic tank level should be approximately 2/3 full
4. Inspect stowage system grippers for loose fittings and components
5. Photo eyes and reflectors should be clean
6. If time permits, drop and retrieve a few cones before driving to jobsite
7. Stow system and turn off before driving at high speeds

1.3.2 Operational Checkout

An operator should be familiar with the machine operation and normal machine sounds. During the operation of the machine, the operator should pay attention to the functionality of the machine and listen for any abnormal sounds. The following is a partial list of items to look and listen for during operation.

1. The cone *retrieval arm* should not attempt to store more than one cone at a time
2. Loose cones on the *stowage system* or stuck on the *lateral conveyor*
3. *Lateral conveyor* continually running
4. System not responding
5. Unscheduled indicator beeping

1.4 ACM Operation

Prior to implementing the ACM, a plan for the closure should be considered. This preparation will help with the initialization of the machine and should describe which side of the machine will be used. For example, when setting a taper from the shoulder and closure of the first lane, the operator may start the taper using the right side of the machine until the taper is complete. The ACM is then driven into the lane to be closed and backed up into the taper. The side of operation is then switched to the left side and the remaining cones are dropped completing the closure. This example is to illustrate how a well planned closure can ease the operation of the ACM and not a recommendation for mode of operation.

In general, operate the switches on the control pendant from the top down for system initialization and from the bottom up for system shutdown.

1.4.1 System Initialization

1. Check that equipment is clear of personnel and other hazards
2. Set signboard or other warning devices
3. Check that the deck is clear
4. Set machine side switch to ‘OFF’

5. Set the ‘PICK/DROP’ switch to the center position
6. Turn on the computer
7. Turn on the System Power
8. Select machine side ‘LEFT’ or ‘RIGHT’
9. If placing cones, select distance ’25, 50, or 100’ and then choose ‘DROP’
10. If retrieving cones, select ‘FORWARD’ or ‘REVERSE’ and the ‘PICK’
11. When operation is complete, set ‘DROP/PICK’ switch to center position
12. Set machine side to ‘OFF’
13. Once the *drop box* is fully retracted, turn off system power
14. Turn off computer

1.4.2 Dropping Cones

The operator should anticipate where the first cone is to be dropped and start several feet before. Once the ‘DROP/PICK’ switch is placed in the drop mode, the system will initialize, grab the first cone, and then release it to be placed. When the cone is traveling on the *lateral conveyor*, the operator should start accelerating the truck forward. To insure even spacing the ACM should be driven at a constant speed. In general the speed of the truck should be as follows.

1. 3-5 MPH for a 25’ spacing
2. 5-7 MPH for a 50’ spacing
3. <18 MPH for a 100’ spacing

The operator can choose to set an extra, or intermediate, cone by moving the ‘DROP/PICK’ switch to the center position and then back to the ‘DROP’ position.

1.4.3 Picking Cones

There are two items to pay close attention to when retrieving cones, the orientation of the cone entering the *primary funnel* and the position of the cone *retrieval arm*. The *primary funnels* are used to knock the cone over and to orientate the cone with the square base end facing the *drop box*. If a cone is already knocked over with the square base facing the *drop box*, the ‘GATE’ button should be pushed just prior to the contact of the cone with the *primary funnel*. Pushing the ‘GATE’ button allows the paddle on the *primary funnel* to float permitting the cone base to pass through the funnel. If the cone is knocked over but not in the right orientation, the paddle is used to stand the cone upright such that the *primary funnel* can turn it over and orientate it properly.

The cone *retrieval arm* grabs the cones from the *secondary funnel* and places them on the *lateral conveyor*. The vehicle speed should be adjusted to allow sufficient time for the arm to finish placing the cone on the *lateral conveyor* and return to the *secondary funnel*. Failure to provide sufficient time will result in a cone being trapped under the *retrieval arm*. If a cone is trapped under the cone *retrieval arm*, the ‘PICK’ switch should be moved to the center position hence, raising the *retrieval arm* and *primary funnel*. Then the truck should be driven a short distance in the opposite direction and the pick mode resumed.

1.4.4 Ending Operation

When the operation is completed, move the 'DROP/PICK' switch into the center position. Set the 'LEFT/RIGHT' switch to the center 'OFF' position. Always work the switches from the bottom up when shutting the system down. Once the *drop box* is stowed turn the system power and computer off. Never drive above 25 MPH with the *drop box* down or the system power turned on.

1.5 Troubleshooting

There are three general ways in which automated equipment malfunction. Equipment fails to start, stops working during the process, or operates in an incorrect manner. The following is a quick reference for troubleshooting ACM malfunctions.

Fault	**Probable Cause**
System Power fails to come on	1. Reset left/right bucket E-stop switches 2. System power relay failure
System fails to initialize	Are both the computer and system power turned on?
Drop box doesn't raise or lower	Check circuit breaker behind passenger seat
System stops responding	1. Limit switch failure 2. Software crash. Turn off, Clear cones and re-boot 3. Low battery voltage
Rear primary funnel deploys with switch in forward mode	Primary funnel relay failure

Appendix
E

AHMCT Advanced Highway Maintenance and Construction Technology Research Center

UCDAVIS Caltrans

AHMCT Release for Field Operational Testing and Evaluation

We, the undersigned, are familiar with the operation of the Automated Cone Machine and we have also visually inspected the machine. Based upon our signatures below, this machine meets our minimum standards for initial testing in actual highway operations. This machine is a first generation prototype, and accordingly, it is intended for limited operation for qualification purposes only. While meeting minimum standards, the attached report documents some limitations and critical inspection points. The machine is a complex automated mechanism, therefore, operators should always receive specific instruction on the safe and proper use of this machine prior to its testing.

AHMCT Center:

5/1/02

Steven A. Velinsky, Director Date

Wil White, Development Engineer 05/01/02

5/01/02

Aaron Raley, Deployment Support

Caltrans Equipment Service Center:

5/1/02

Date

Date

Caltrans New Technology & Research:

Juan Araya, Program Manager Date

Robert Battersby, Project Manager

Caltrans Maintenance District :

Date

Machine Limitations

1. The ACM was designed to work with 28“ cones that have had the raised rubber feet removed. Using any other configuration cone may cause malfunction of the system or damage.

2. While in operation, there is minimal clearance from the drop-box to the ground. In addition, the drop-box extends off the side of the vehicle. Obstacles and un-even ground should be avoided. The operator must avoid impacting uneven surfaces and other obstacles.

3. In the Drop-Off and Pick-Up mode, the ACM has minimum and maximum speeds at which it works ideally. Refer to the Operator’s Manual.

4. The maximum cone capacity is 80 cones, 40 per stack.

Critical Inspection Points

1. The hydraulic hoses on the gripper assemblies are subject to loosening and can develop leaks.

2. The V-Track Wheels on the gripper assemblies can break and possibly cause further damage. They should be inspected periodically.

Notes

The Machine Limitations and Critical Inspection Points lists do not represent either a set of operating instructions or recommended maintenance schedule and/or procedure. Refer to the appropriate documentation for operating instructions and maintenance information.